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Assessment of shallow-water habitat mapping tools and methods

A pilot study at Fire Island National Seashore

Natural Resource Technical Report NPS/NERO/NRTR—2010/323

ON THE COVER
Sediment Profile Image (SPI), coarse sand with *Ruppia*.
Image courtesy of: Emily Schumchenia, University of Rhode Island

Assessment of shallow-water habitat mapping tools and methods

A pilot study at Fire Island National Seashore

Natural Resource Technical Report NPS/NERO/NRTR—2010/323

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Executive summary

A pilot study to develop a protocol for habitat mapping in very shallow water (0-5 meters deep) was undertaken by a team of scientists from the University of Rhode Island, Washington College, and the National Park Service, August 13-21, 2006 in a portion of Great South Bay at the Fire Island National Seashore. The main goals of the pilot study were to test acoustic (sidescan sonar, single-beam sonar and interferometric sonar) and ground-truthing (grab samples, sediment profile imagery, underwater video) methods to map marine Park habitats in very shallow water, classify habitats using NOAA's Coastal and Marine Ecological Classification Standard (CMECS), and provide a general framework to the NPS managers for estimating the time and resources needed for marine habitat mapping within coastal National Parks. Despite the short-term nature of the project, the majority of methods produced detailed habitat information. We show that the technology now exists to do geological and biological habitat mapping in shallow waters, and that a simple statistical examination of the acoustic, geological and biological data allowed ecologically-relevant patterns to emerge. The current version of CMECS was limited in its ability to classify subtle but potentially important changes in habitat, but updates to this version since the study period, and future revisions, will likely address these shortcomings. A habitat mapping effort that employs multiple tools, utilizes a statistically-guided sampling approach and a classification scheme that can incorporate newly discovered ecological associations and adapt to growing datasets will be vital to the National Park Service's marine mapping and classification efforts.

Introduction

A pilot study to develop a protocol for habitat mapping in very shallow water (0-5 meters deep) was undertaken by a team of scientists from the University of Rhode Island (URI), Washington College, and the National Park Service. In addition, engineers from GeoAcoustics and Measurtronics assisted with set up and testing of their specific mapping instruments. The pilot study was done between August 13-21, 2006 in a portion of Great South Bay north of the Fire Island barrier between Long Cove and Watch Hill. The study area was selected by an examination of aerial photographs because it appeared to contain a diversity of habitats, including submerged aquatic vegetation (SAV).

Study Goals

There were four major goals of the pilot study. They were: (1) determine the feasibility of mapping with side scan sonar and interferometric sonar, which produces bathymetry and sidescan simultaneously, and their relative performance in very shallow water (0-5m deep); (2) test approaches to ground truthing the sonar data and cost-effectively identifying habitat types; (3) test and compare different approaches to habitat classification including NOAA's version III draft of the Coastal and Marine Ecological Classification Scheme (Madden et al., 2009); and (4) provide a general framework to the NPS managers for estimating the time and resources needed for marine habitat mapping within coastal National Parks.

General Approach

URI has an ongoing habitat mapping project in Rhode Island (RI) coastal waters funded by RI Sea Grant called BayMap. The protocol for the BayMap project is shown in Figure 1. We used a scaled down version of the BayMap protocol in the Fire Island National Seashore pilot study. In addition, we were confident that side scan sonar would work as a bottom type mapping tool in shallow waters based on previous studies. On the other hand, obtaining bathymetry data in shallow water is difficult. During the pilot study we tested a relatively new technology, interferometric sonar, to simultaneously map bathymetry and bottom type via side scan sonar. We tested a GeoAcoustics Geoswath Plus system in this study, but other shallow water interferometric systems would provide comparable results (see Appendix A).

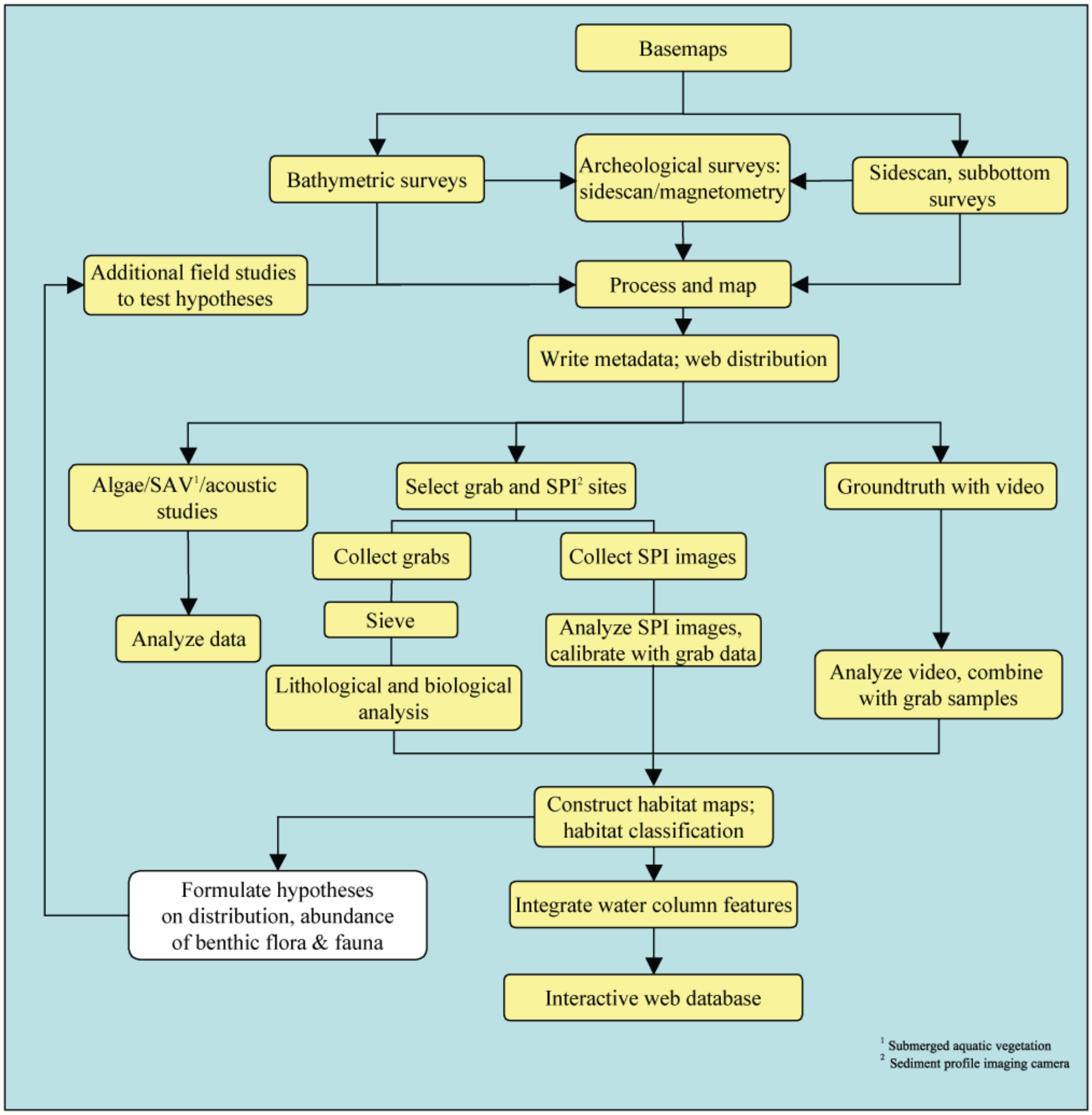

Figure 1. Flowchart of the BayMap mapping protocol.

Methods

Acoustics: Side scan sonar, single beam sonar, interferometric sonar

Side scan sonar imagery was collected on August 16, 2006. Side scan data were acquired using an Edgetech Model 670C Towfish with dual simultaneous 100 & 400 kHz full spectrum side scan sonar and a Model 563 topside processor with Discover Side scan Sonar software. With swath widths of 40m on each channel for high frequency/75m low frequency, and parallel line spacing set at 80m, approximately 100% data coverage was achieved. Data were processed using Chesapeake Tech SonarWeb PRO version 3.16. After beam angle correction, slant range correction and bottom tracking, a mosaic was created at 0.3 meter pixel size. Navigational data were recorded by a Trimble DSM212L differential GPS with sub-meter accuracy and input to the Discover acquisition software, and automatically integrated into the mosaic. This process produced a uniform image of the seafloor with dark colors indicating low backscatter, or fine-grained sediments, and lighter colors indicating high backscatter, or harder substrates such as boulders. Because of choppy sea state during the survey, the acoustic data collected from points furthest from the sensor were of poor quality. For this reason, the range of each swath was trimmed to remove noisy data and the final mosaic contained slivers of “missing” data. The side scan data were further processed using the Quester Tangent Corporation (QTC) software SIDEVIEW to statistically determine areas containing unique acoustic properties (e.g., backscatter intensity, backscatter diversity). A maximum of 10 classes was allowed, and the software used a cluster analysis algorithm to calculate the optimal number of classes. The sidescan mosaic and SIDEVIEW classification can be seen in Figure 2.

On August 17, 2006, the same transect lines were re-traced with the QTC VIEW V single beam sonar system operating at 200 kHz. The single beam system generates a continuous series of acoustic back scatter points, each with a foot-print of between 0.5 and 1.3 m2 (depending on the water depth). Because single beam sonar systems generate a series of single points on the seafloor along the survey transect, much more interpolation is necessary when compared with side scan sonar. With the line spacing used in this study, seafloor coverage with the single beam system is on the order of 10-20%, whereas the sidescan achieved 100%. The single beam system, however, is a lighter instrument and can be deployed on practically any survey platform, and has the potential to be calibrated to map the specific bottom types present in each individual survey area. Side scan sonar instrumentation is much larger and cannot be calibrated in a similar way. The single beam sonar data were classified into groups containing unique acoustic properties, using the QTC software IMPACT, a program for processing single beam data that uses a protocol similar to SIDEVIEW (Figure 3).

On August 17, 2006, a GeoSwath interferometric sonar system was tested by retracing some of the original sonar transects, but also expanding the survey area into shallower water. This test is described in detail in Appendix A.

Figure 2. Sidescan sonar mosaic and classified product from Quester Tangent Corporation SIDEVIEW analysis. Colors represent statistically distinct acoustic classes.

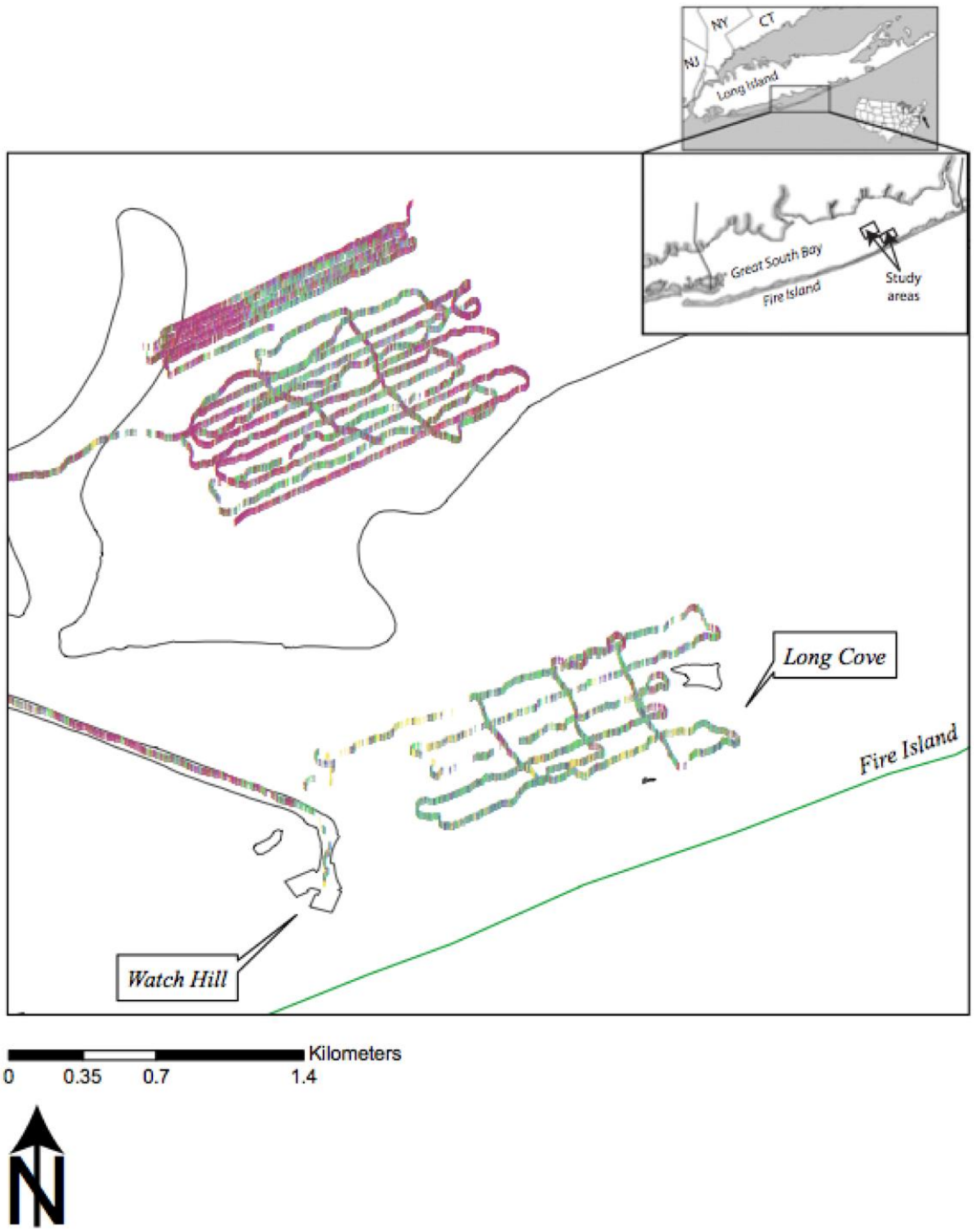

Figure 3. Single beam sonar transects and classified product from Quester Tangent Corporation IMPACT analysis. Colors represent statistically distinct acoustic signatures.

Ground-truthing: Grab samples, sediment profile imagery, underwater video

Acoustic data must be interpreted in the context of ground-truth samples. Sampling stations for ground-truth were stratified based on visible changes in backscatter intensity visible in the sidescan sonar mosaic. Due to limits on time and resources, 15 stations were selected for ground-truth, with at least one station in each backscatter unit. Normally, at least three replicate samples per backscatter unit would be collected in order to account for statistical variance in the samples. Ground-truthing methods in this study consisted of bottom grab samples, sediment profile imagery (SPI), and underwater video. One grab sample, two replicate SPI camera drops and several minutes of underwater video were collected at each station. Collecting samples at the 15 stations took less than one 8-hour day (Figure 4 and Appendix B).

Grab samples can provide information about surficial and sub-surficial sediment type and biological communities. For this study, resources were not available for benthic biology studies. SPI images provide this same information, but in undisturbed form (so that organism-sediment relationships may be examined) and much more rapidly. Underwater video provides information about surficial habitat only – but often, detailed estimates of percent cover and population density can be made over large areas (e.g., Hewitt et al. 2004). Grab samples were taken with a petite Ponar grab (2.2L volume, 0.023 m^2 sampling area) and sub-sampled for laboratory grain size analysis.

A SPI camera, consisting of an inverted-periscope attached to a landing frame was lowered onto the sediment surface at each station. A rectangular prism entered the sediment to a maximum depth of 20 cm (depending on grain size and sediment compaction). A digital camera within the prism housing took a photograph of the cross-section of the sediment-water interface that was in contact with the prism window (see Figure 5). These pictures can be used to rapidly obtain a suite of habitat characteristics that may not be visible using other methods, such as the presence of bioturbating organisms, the depth of oxygen penetration into the sediment (an indicator of bottom-water oxygenation and bioturbation depth), presence of epifaunal organisms, such as snails or tube worms, and the presence of macroalgae or seagrass.

An Applied Microvideo M-225 underwater video camera was dropped and towed for several minutes at the 15 ground-truth stations. Test-drops at each station revealed that the water was too turbid to record a view of the seafloor. For this reason, no interpretable data were recovered using this method. Normally, two laptops would be time-synched for this survey - one recording video and one recording navigational data from a Trimble DGPS. The two data sets would be combined in Microsoft Excel, using the time-synch as the link between video observations and GPS coordinates. In the lab, video would be played back, with notations made about what the viewer observed at least every 30 seconds. Observations such as percent cover of vegetation, bottom type (e.g., mud, sand, cobble), and presence of any organisms would be noted.

Once raw data collection in the field was complete, analysis of the data was conducted. Digital sonar data were analyzed using QTC SIDEVIEW (for sidescan) and IMPACT (for single beam) software packages to determine the number and characteristics of unique acoustic classes present in the study area, as described above. Sediment samples were analyzed using the Mastersizer 2000 to yield grain size and sorting information. SPI images were interpreted for dominant species (SAV+epifauna) and depth of sediment oxidation (aRPD depth). These analyzed data still represent a simple inventory; georeferenced versions of these data can be overlaid on a map, but do not constitute a “habitat map” until relationships between the individual components are demonstrated. An integrated habitat map provides context for each abiotic and biotic data layer such that potentially important patterns and relationships are displayed.

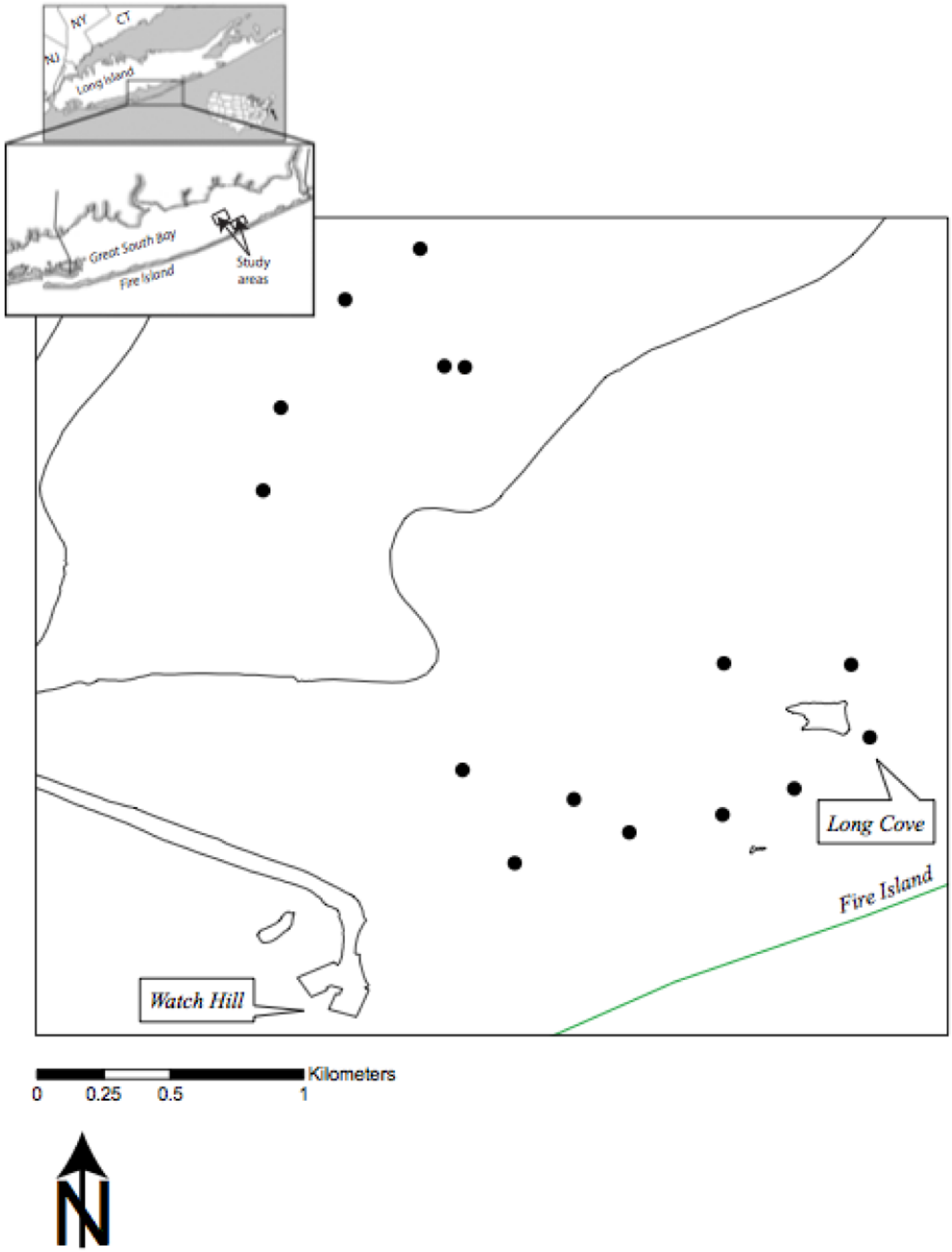

Figure 4. Ground-truth sampling stations for Great South Bay mapping study.

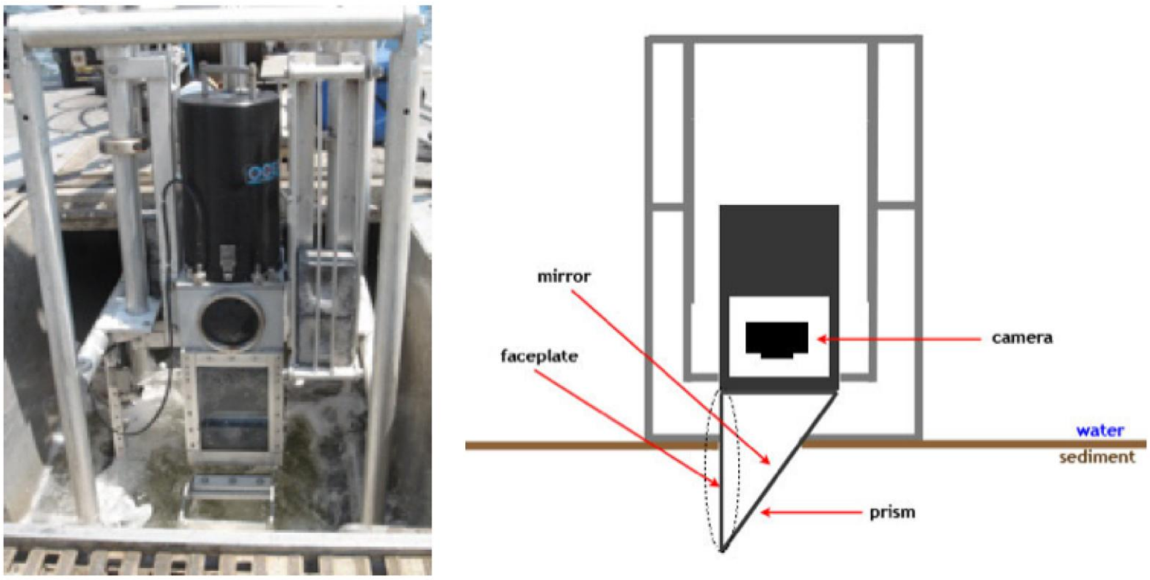

Figure 5. Sediment profile imagery camera front view, and side-view schematic showing deployment in sediment.

Results

Instrumentation

All methods worked well except underwater video due to a significant brown tide event during the pilot study. Interferometric sonar worked well in shallow water (see Appendix A) and provides both swath bathymetry and side scan sonar data. The relatively wide swath (8 times the water depth) provided by interferometric sonar in shallow water argues for it being a more cost-effective approach than multibeam mapping with a relatively narrow swath (4 times the water depth). SPI surveys done in conjunction with grab samples proved to be a useful and rapid ground-truth approach.

Habitat mapping

Two approaches were utilized in integrating the data layers: a top-down approach and a bottom-up approach (e.g. Hewitt et al. 2004).

The top-down approach takes broad-scale habitat units defined by the acoustic signatures and determines, using the ground-truth samples, if unique abiotic (grain size) and biotic (SAV+epifauna) groups exist within these units. If unique grainsize/SAV+epifauna groups do exist within acoustic signatures, then this would indicate that acoustic methods (side scan sonar, single beam sonar) could be used to infer grainsize/SAV+epifauna groups within the study area, and perhaps beyond. A top-down map will be defined by acoustic signature units that are described by discreet grainsize/SAV+epifauna associations. For example, "medium-intensity mottled backscatter units represent fine sand with *Zostera marina* beds."

The bottom-up approach begins with the abiotic and biotic data collected at each ground-truth station across the study area and uses a cluster analysis to determine distinct groups of stations that have similar grainsize and/or SAV+epifauna characteristics. This exercise often results in a different number of initial groups than the top-down method. If abiotic and biotic data are very diverse (representing a wide range of grain sizes and biological communities), then there could be many more bottom-up groups than top-down groups. These groups are then tested to determine if they possess unique acoustic properties. If there are unique acoustic properties for each bottom-up group, then this would again indicate that the abiotic and biotic data can be easily mapped using acoustic methods. It is more likely that only one or a few grainsize/SAV+epifauna groups have unique acoustic properties, and several others are acoustically indistinguishable (due to lack of structural/textural features, or similar structure/texture). A bottom-up map will be defined by abiotic/biotic units that are described by their discreet acoustic properties. For example "fine sand with *Zostera marina* beds are found in medium-intensity mottled backscatter and in high-intensity mottled backscatter."

The statistical software package used for these analyses was PRIMER version 6.0. The cluster analysis for the bottom-up approach was performed using the CLUSTER function. The tests for similarity between acoustic and abiotic/biotic groups were performed with the Analysis of Similarity (ANOSIM) function.

For the top-down approach, a matrix of between-sample similarity (Bray-Curtis similarity index) was calculated using the presence and absence of *Zostera marina*, *Ruppia maritima*, *Ampelisca abdita*, and the depth of oxidized sediment as measured in SPI images at each station (biotic data alone). Another similarity matrix was calculated in the same way using just grain size parameters measured at each station (abiotic data alone). The abiotic/biotic data from each station were combined to create a third similarity matrix representing the combination of grainsize/SAV+epifauna data. Each station was labeled with the SIDEVIEW (side scan) or IMPACT (single beam) class (defined by the QTC software) that was statistically calculated for each station by each software package (Table 1 for example). A one-way ANOSIM was run on each similarity matrix to test whether or not the SIDEVIEW or IMPACT classes contained statistically significant biotic assemblages, abiotic assemblages or abiotic/biotic assemblages (Table 2).

For the bottom-up approach, cluster analysis was run for biotic data alone, abiotic data alone and a dataset composed of both abiotic and biotic datasets for each station. For each cluster analysis, between 1 and 15 clusters were generated. The Similarity Profile (SIMPROF) function was used to aid in determining a statistically distinct number of clusters for each analysis. For the biotic data alone, four clusters were identified (a, b, c, d), 3 clusters were identified based on the abiotic data alone (e, f, g), and 4 clusters were identified when the abiotic and biotic data were combined (h, i, j, k) (Figures 6 – 8).

Next, two matrices of between-sample similarity (Euclidean distance) were calculated using the Q-values (first three principal components) generated by each SIDEVIEW and IMPACT analysis. Q-values are the result of a reduction of dimensionality of 132 variables derived from each acoustic dataset, including backscatter mean, standard deviation, skewness, kurtosis, power spectrum and histogram (Preston, 2008). Each station was labeled with the abiotic, biotic or abiotic+biotic cluster that was generated (Table 3 for example). A one-way ANOSIM was run on each similarity matrix to test whether or not the abiotic, biotic or abiotic/biotic clusters contained statistically significant acoustic properties (Table 4 for results).

Table 1. Example data inputs for the top-down approach utilizing biotic data alone. SIDEVIEW class and IMPACT class refer to the statistical analyses performed using the Quester Tangent Corp. (QTC) software packages for classifying side scan sonar and single beam sonar data, respectively.

Station	*Zostera*	*Ruppia*	*Ampelisca*	Ox sed (cm)	SIDEVIEW class	IMPACT class
1	+		+	3.714	1	-
2				0.702	9	7
3		+		1.088	1	5
4	+	+		0.430	3	6
5	+			0.485	3	5
6				0.634	9	8
7				0.265	9	4
8	+	+		0.265	7	5
9		+		0.149	1	1
10				0.200	3	7
11			+	0.820	6	6
12			+	1.384	3	7
13			+	1.507	6	5
14		+	+	0.844	6	5
15		+	+	0.739	1	7

Table 2. Results of the top-down ANOSIM.

	ANOSIM R	p
Biotic alone		
SIDEVIEW	0.239	0.045
IMPACT	-0.045	0.594
Abiotic alone		
SIDEVIEW	-0.097	0.777
IMPACT	-0.102	0.676
Biotic+Abiotic		
SIDEVIEW	0.032	0.382
IMPACT	-0.152	0.791

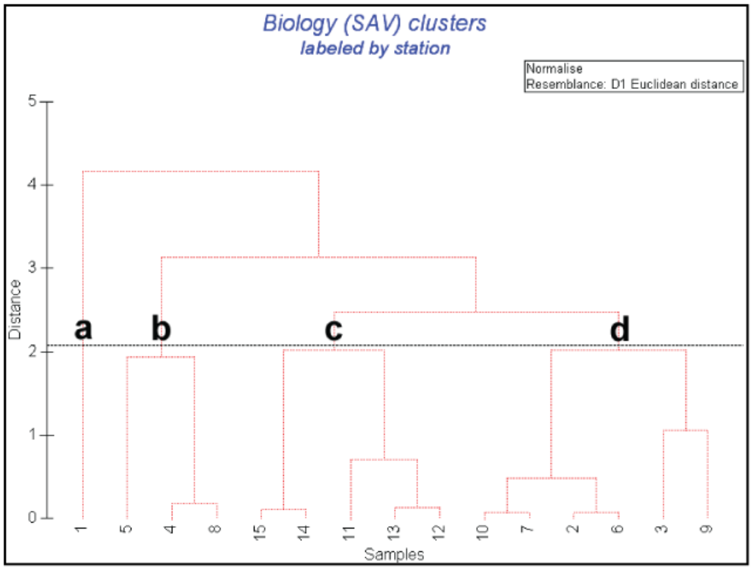

Figure 6. Cluster diagram generated using biotic (SAV+epifauna) data alone in PRIMER version 6.0.

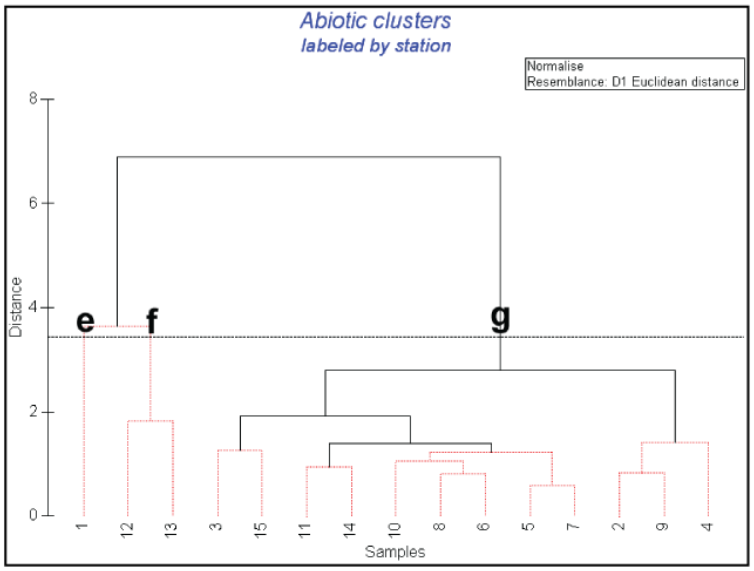

Figure 7. Cluster diagram generated using abiotic(grain size) data alone in PRIMER version 6.0.

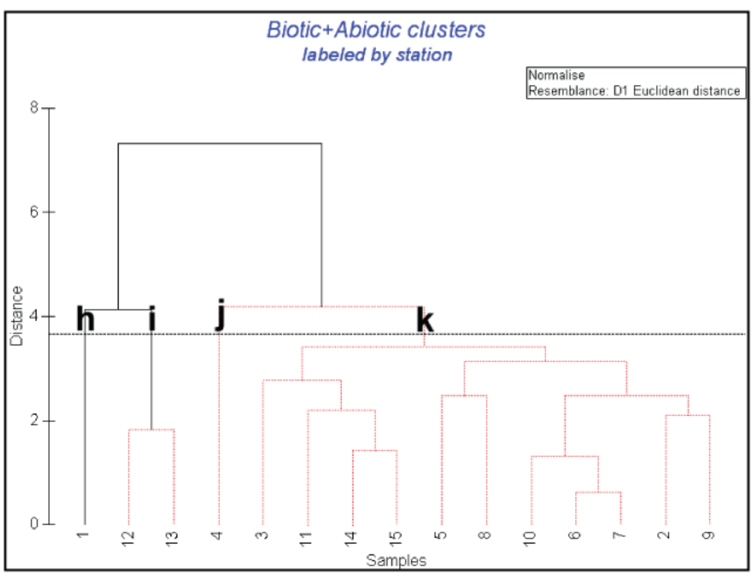

Figure 8. Cluster diagram generated using biotic (SAV+epifauna) and abiotic (grain size) data in PRIMER version 6.0.

Figure 6, 7, 8: Cluster Diagrams

Table 3. Example data inputs for the bottom-up approach. Cluster labels refer to clusters shown in Figures 6-8.

Station	SIDEVIEW Q-value	IMPACT Q-value	Biotic clusters	Abiotic clusters	Biotic+Abiotic clusters
1	9.082	-2.121	a	e	h
2	8.355	-1.564	d	g	k
3	-4.818	-1.266	d	g	k
4	7.949	-1.715	b	g	j
5	6.010	-1.553	b	g	k
6	8.123	-2.163	d	g	k
7	8.896	-2.053	d	g	k
8	7.971	-1.559	b	g	k
9	8.976	0.200	d	g	k
10	7.653	-1.873	d	g	k
11	7.703	-1.546	c	g	k
12	7.239	-2.096	c	f	i
13	7.485	-1.168	c	f	i
14	-3.249	-1.339	c	g	k
15	9.589	-2.079	c	g	k

Table 4. Results of bottom-up ANOSIM.

	ANOSIM R	p
Biotic clusters		
SIDEVIEW Q-values	0.135	0.04
IMPACT Q-values	0.151	0.04
Abiotic clusters		
SIDEVIEW Q-values	0.231	0.09
IMPACT Q-values	0.09	0.259
Biotic+Abiotic clusters		
SIDEVIEW Q-values	0.109	0.219
IMPACT Q-values	-0.004	0.475

Results and discussion

The top-down approach yielded one significant result. There are statistically significant biotic groups within the broad-scale SIDEVIEW acoustic signature units (Table 2; $R=0.239$ $p=0.045$). The fairly low R value indicates that the relationship is not very strong, but the p value indicates that the relationship is significant. This relationship between acoustic properties and biotic characteristics is reinforced by significant results from the bottom-up approach as well (Table 4). The biotic clusters contain statistically similar acoustic properties (both from SIDEVIEW side scan sonar and IMPACT single beam). Again, the relationships are weak ($R=0.135$ for SIDEVIEW Q-values; 0.151 for IMPACT Q-values) but significant ($p=0.04$ for both SIDEVIEW and IMPACT). Because neither abiotic characteristics alone, nor a combination of abiotic/biotic characteristics displayed significant relationships to acoustic properties, it can be hypothesized that SAV+epifauna in this study area greatly influence the acoustic response of the seafloor, and thus may be effectively mapped using acoustic tools. This influence of biota is most likely due to the fact that abiotic (grain size) characteristics do not vary widely across the study area, and thus do not adequately discriminate between sites. For example, for the 15 ground-truth sites in this study, grain size (Φ) ranged from 0.76 to 2.96, whereas in a coastal lagoon in southern Rhode Island, grain sizes were between 1.0 and > 8.0 (Ford, 2003).

Because of the time constraints and cost limitations associated with this pilot study, it was not possible to map continuous biological habitat units. Instead, this study relied on the information collected at the 15 point samples. If high turbidity did not prevent the use of underwater video, then continuous SAV habitats could have been delineated. Furthermore, it is not reliable to assume that patches of SAV and epifauna (e.g. *Ampelisca*) and infauna correspond to changes in the abiotic environment (surficial geology) (Diaz et al. 2004). Therefore, this study did not extrapolate biological characteristics beyond the 15 individual point locations. Surely, biologically important information is embedded within the SIDEVIEW and IMPACT statistical analyses, but more ground-truth points (at least 3 points per acoustic class) would be needed to statistically describe and distinguish the biological habitats. Another day of ground-truth studies would have provided sufficient information to map biological habitats. Furthermore, underwater video studies would normally have worked within the study area.

Two habitat classification schemes were used to classify habitat data in the pilot study. The first scheme is the draft of CMECS III (Madden et al. 2009), and the second is a scheme proposed to facilitate ecosystem-based management (EBM; Guarinello et al. 2010). The EBM scheme was developed to fully incorporate spatial and temporal habitat complexity, acknowledge the multi-scale hierarchical nature of marine habitats, and be easily communicated to a wide audience. A comparison of the CMECS III draft and the EBM scheme is outlined in Table 5.

A habitat map was created using GIS data from previous studies (provided by NOAA Coastal Services Center [2003]), and classified using the draft version III of CMECS. It is noted that the level of detail is quite coarse (Figure 9, Table 6). Furthermore, the NOAA data do not provide a description of the surficial geology beneath the SAV. Thus, the abiotic (substrate) portion of habitat units containing SAV is not described in either the classification or the map.

Despite the limitations in extrapolating this study's biological data, a habitat map was created and also classified using CMECS III (Table 7 and Figure 10). In addition, this study's data were

Table 5. Side-by-side comparison of CMECS III (Madden et al., 2009) and the proposed framework (Guarinello et al. 2010).

CMECS III			Proposed Framework		
			3.3.1 Large Marine Ecosystem *3.3.2* System *3.3.3* Formation: Mega/Mesogeoform Mega/Mesohydroform		
COMPONENTS			*3.4* COMPONENT TREE		
Benthic Cover	Water Column	Geoform	Benthic	Water Column	Human
System	System	Mega-geoform	*3.4.1* Structural Environment -macrogeoform	*3.4.1* Structural Environment -macro-hydroform	*3.4.1* Structural Environment
Sub-system	Depth Zone	Meso-geoform			
Cover Type	Structure	Macro-geoform	*3.4.2* Habitat – abiotic & biotic	*3.4.2* Habitat – abiotic & biotic	*3.4.2* Habitat – use & action
Class	Macrohydroform	Micro-geoform			
Subclass	Mesohydroform	Anthropogenic	*3.4.2.1* Characterization	*3.4.2.1* Characterization	*3.4.2.1* Characterization

Table 5: Continued

CMECS III			Proposed Framework		
		geoform	– substrate properties, (microgeoform), functional group	– water column properties, functional group	– type of use & action
Group	Lifeform				
Biotope	Biotope		*3.4.2.2* Data Analyses – quantitative & qualitative	*3.4.2.2* Data Analyses – quantitative & qualitative	*3.4.2.2* Specifics – use & action

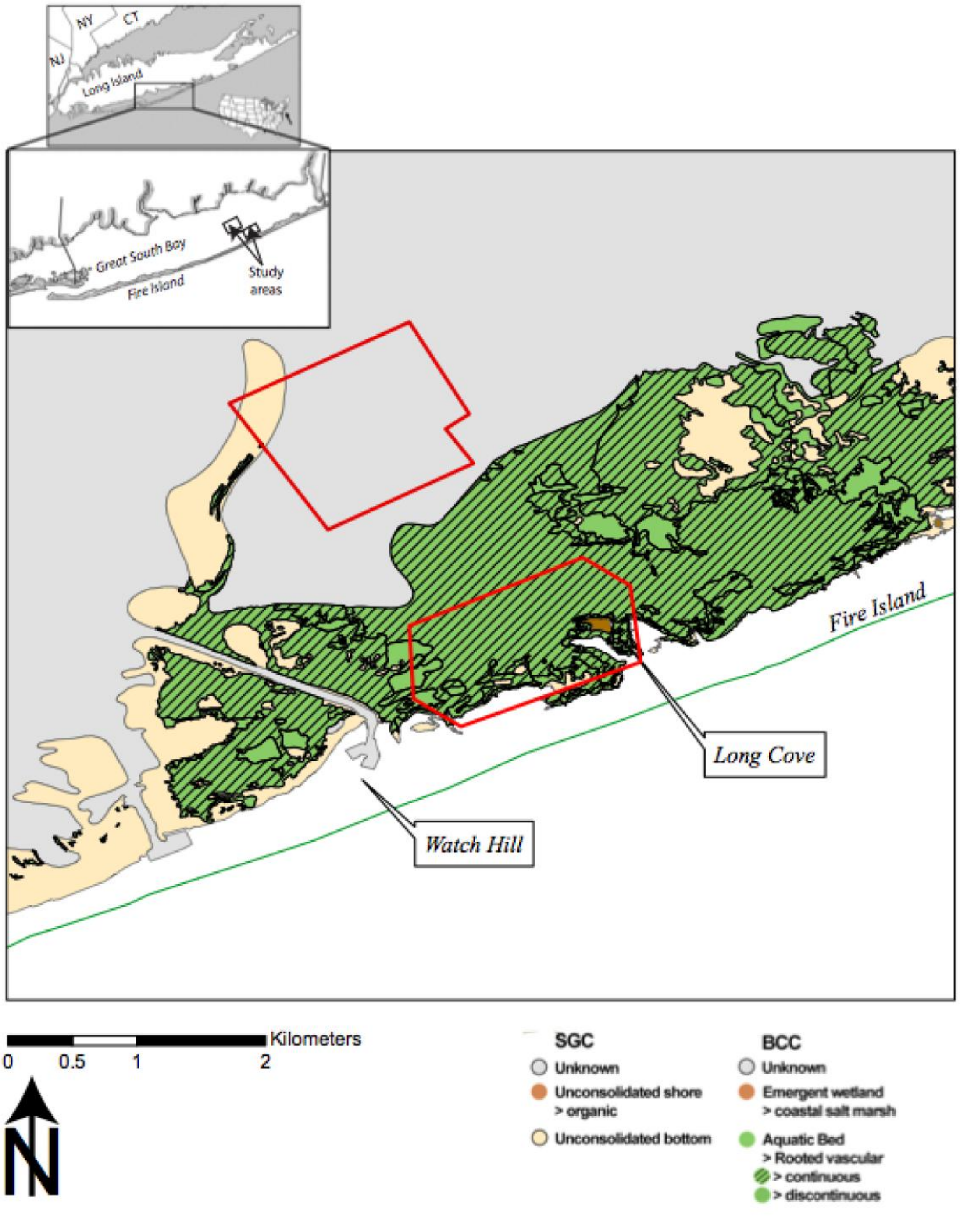

Figure 9. Benthic habitat map created using NOAA CSC GIS data of Great South Bay study areas, and using the CMECS III Surficial Geology Component (SGC) overlaid with the Benthic Cover Component (BCC). ">" indicates subsequent levels of the hierarchy as in Table 5.

Table 6. Benthic habitat classification (using NOAA CMECS III) of Great South Bay study areas using GIS data provided by NOAA Coastal Services Center. “>” denotes next lower hierarchical level.

<table>
<tr><td colspan="3">System: Estuarine [ES], Landward [Lndw], Enclosed [encl], Virginian ecoregion</td></tr>
<tr><td colspan="3">Subsystem: Subtidal [1]</td></tr>
<tr><td>Surficial Geology</td><td>Benthic Cover</td><td>Geoform</td></tr>
<tr><td>Class: Unconsolidated bottom [UB]
Class: Unconsolidated shore [US]</td><td rowspan="2">Class: Emergent wetland [EM]
> Subclass: Coastal salt marsh [1]
Class: Aquatic bed [AB]
> Subclass: Rooted vascular [3]
> modifier: discontinuous
> modifier: continuous</td><td>Physiographic province: Enclosed sea [11]
> Geoform: Lagoon [n]; coastal lagoon</td></tr>
<tr><td>> Subclass: organic [4]</td><td></td></tr>
</table>

Table 7. Benthic habitat classification of Great South Bay study areas using data collected by this study and following CMECS III. “>” denotes next lower hierarchical level.

<table>
<tr><td colspan="3">System: Estuarine [ES], Landward [Lndw], Enclosed [encl], Virginian ecoregion</td></tr>
<tr><td colspan="3">Subsystem: Subtidal [1]</td></tr>
<tr><td>Surficial Geology</td><td>Benthic Cover</td><td>Geoform</td></tr>
<tr><td>Class: Unconsolidated bottom [UB]
> Subclass: Sands [2]</td><td rowspan="2">Class: Faunal bed [FB]
> Subclass: Sessile epifauna [1]
> Biotic group: small tube building fauna [st]
> Biotope: Ampelisca community
Class: Aquatic bed [AB]
> Subclass: Rooted vascular [3]
> Biotic group: Ruppia seagrass bed [rp]
> Biotope: Ruppia maritima temperate seagrass bed
> Biotic group: Zostera seagrass bed [zs]
> Biotope: Zostera marina seagrass bed
> Biotic group: Zostera with Ruppia understory</td><td>Physiographic province: Enclosed sea [11]
> Geoform: Lagoon [n]; coastal lagoon</td></tr>
<tr><td></td><td></td></tr>
</table>

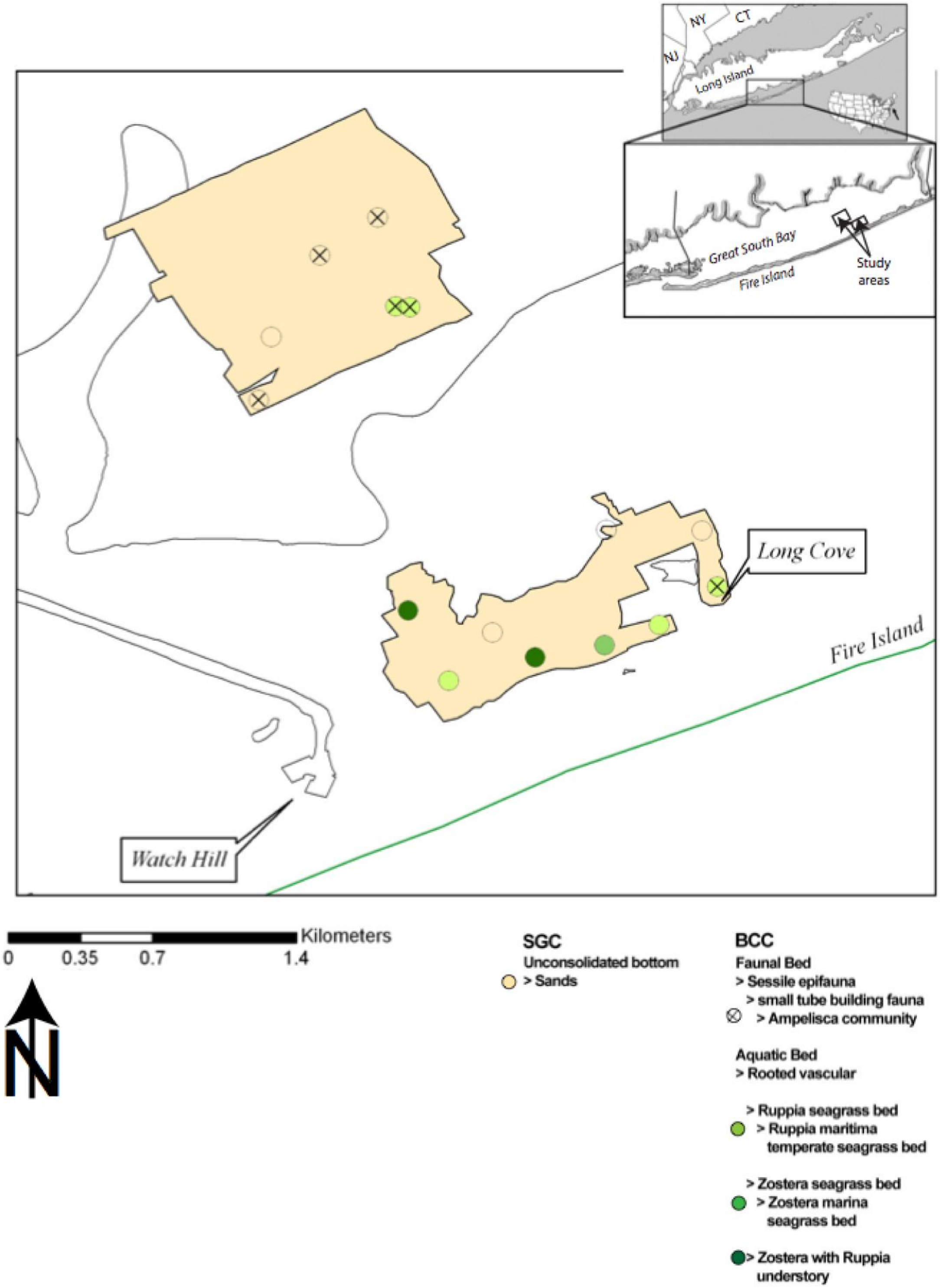

Figure 10. Benthic habitat map for this study's Great South Bay data using CMECS III Surficial Geology Component (SGC) overlaid with Benthic Cover Component (BCC). ">" indicate subsequent levels of the hierarchy as in Table 6.

mapped and classified using the proposed modification to CMECS, which provides more detail and ecological context (Guarinello et al. 2010; Figure 11 and Table 8).

Sampling at finer-resolution allowed this study's data to be used to classify Biotic Groups and Biotopes for many of the sampling stations, whereas NOAA's data, collected at a much broader scale, could only be used to classify habitat to the Subclass level. A large area within this study's boundaries was classified as "unknown" by NOAA, but many of their polygon boundaries match the broad-scale acoustic boundaries delineated by this study. The NOAA data did not differentiate seagrass species, whereas this study documented three distinct seagrass Biotic Groups: *Ruppia* seagrass bed, *Zostera* seagrass bed, and a newly-defined *Zostera* with *Ruppia* understory. This level of classification detail provides valuable information for habitat quality assessments, especially if *Ruppia* presence in some *Zostera* beds of Great South Bay indicates stress to *Zostera*, as has been documented elsewhere (Johnson et al. 2003).

The differences between the CMECS III classification (Madden et al. 2009) of this study's data and the EBM scheme may also be important for resource management or further mapping activities. For example, the CMECS III classification could delineate only one Surficial Geology Class and Subclass for the entire study area – "Sands", whereas the modified scheme allows for at least three abiotic habitat types to be delineated – fine sand, medium sand, and coarse sand. Although the SAV+epifauna mapped in this study did not seem to differentiate based on this gradient of substrates, a more detailed mapping study could examine the differences between infaunal benthic communities in these three abiotic habitats. If a difference between these substrate types and benthic communities proved to be significant, then it would have implications for contaminant susceptibility, nutrient cycling, dredging impacts, and a number of other ecological and anthropogenic factors.

The classification for the EBM scheme (Table 8) allows for the reporting of quantitative data (e.g., % sand, depth of oxidized sediment (aRPD)), in addition to the textual characterizations present in both the modified scheme and CMECS III. Perhaps most importantly, these lower levels of the EBM scheme are intended to be a user-defined group of continuous variables (as opposed to categorical variables). If percent cover data for seagrass species or epifauna were collected, or a measure of shoot density, organic carbon, or wet weight, then these could be documented in the EBM scheme's table and incorporated into the map as well. Several studies of the classification of species-environment relationships advocate for this approach adopted by the EBM scheme (Guarinello et al. 2010) of treating variables as continuous, rather than categorical (as CMECS does) (Wu et al. 2000, McGarigal and Cushman 2005). By reporting variables continuously, one does not have to arbitrarily choose boundaries that may turn out to have little ecological meaning. Acknowledging this level of detail in both mapping and classification products is more meaningful for making comparisons with historical data, and for setting management and/or restoration goals (Guarinello et al. 2010). Without a doubt, as the number of habitat inventories across ecosystems increases, the number of unique and new ecologically relevant patterns emerging will increase as well, and a flexible classification scheme that can incorporate newly discovered ecological associations and adapt to growing datasets will be vital to the National Park Service's marine mapping and classification efforts.

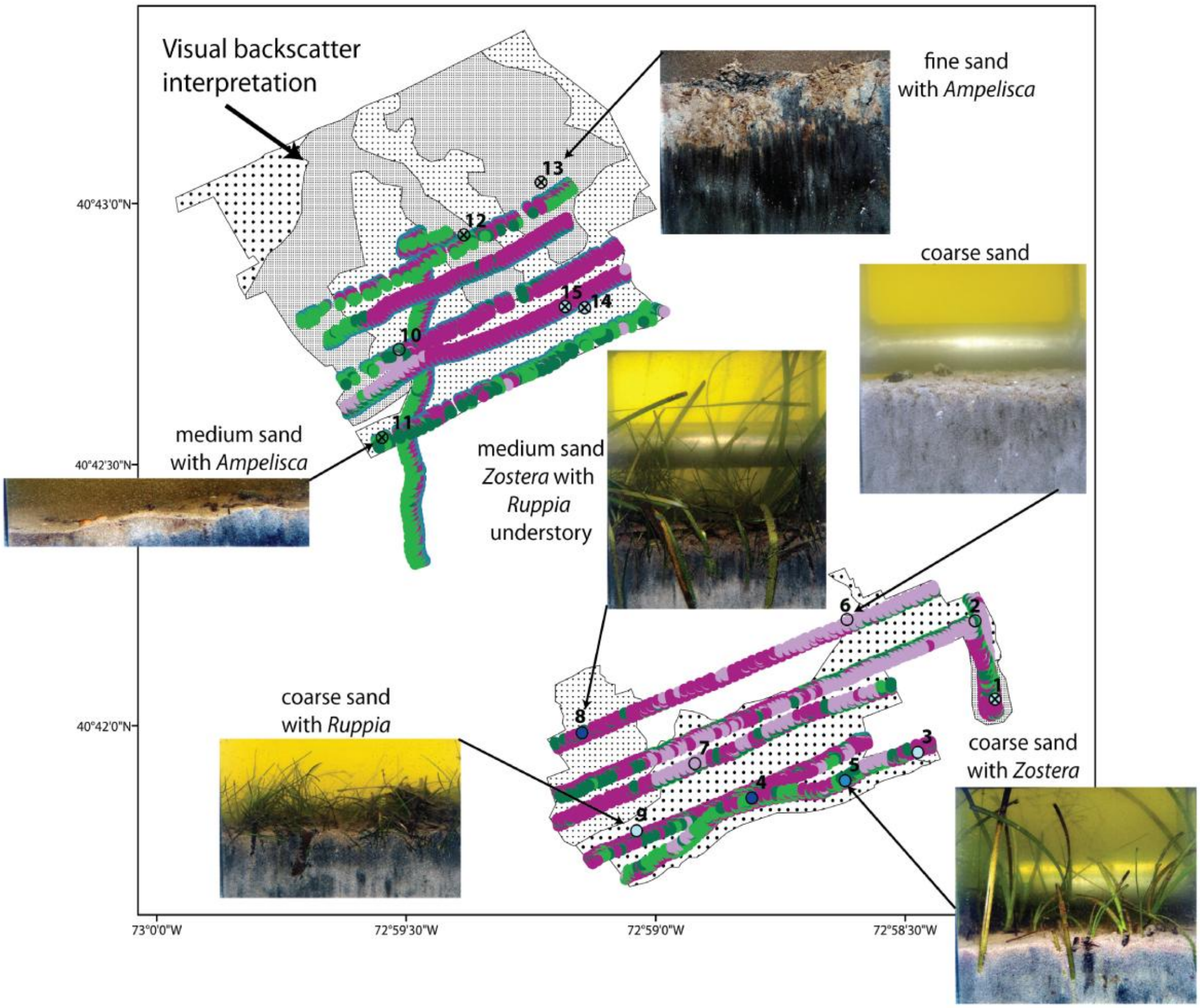

Figure 11. Benthic habitat map of Great South Bay study areas using modified version of CMECS III standard proposed by Guarinello et al. (2010). Use Table 7 as legend. Study area extents are same as Figs. 9 & 10. Sediment profile images (SPI) show examples of described habitat types

Table 8. Benthic habitat classification of Great South Bay study areas using modified habitat classification scheme from Guarinello et al. (2010). Use as legend for Figure 6.

Large Marine Ecosystem: Northeast U.S. Continental Shelf
System: Estuarine
Formation: Coastal lagoon

SIDEVIEW cluster groups	1				3				6			7	9		
SPI cluster groups	A	D	D	C	B	B	D	C	C	C	C	B	D	D	D
Ground-truth sites	1	3	9	15	4	5	10	12	13	14	11	8	2	6	7
Benthic Habitat- abiotic															
Characterization:															
fine sand															
med sand															
coarse sand															
Data analyses, quantitative:															
% very fine sand	15	0.5	0	2.3	0	0	0.8	24	31	1.1	3.4	0	0	0	0
Sorting	poor	mod	well	mod	well	mod	well	poor	poor	mod	mod	well	well	well	well
Benthic Habitat- biotic															
Characterization:															
Ruppia															
Zostera															
Ampelisca	X			X			X	X	X		X				
Data analyses, quantitative:															
aRPD depth (cm)	3.7	1.1	0.1	0.7	0.4	0.5	0.2	1.4	1.5	0.8	0.8	0.3	0.7	0.6	0.3

Conclusions

1. We have shown that the technology now exists to do geological and biological habitat mapping in shallow (0-5 m) waters. Broad-scale acoustic datasets, such as interferometric sonar and side scan sonar, provide a base layer for both geologic and biological habitat mapping and ecological pattern interpretation. Single beam sonar is an effective acoustic method, but the smaller footprint size makes it a less efficient option if either interferometric, or side scan sonar is available.
2. Interferometric sonar systems, such as the GeoAcoustics GeoSwath Plus (and others) are effective and efficient instruments for rapidly attaining both sidescan sonar and bathymetry data in very shallow water.
3. Ground-truthing methods such as SPI and grab samples provide rapid and essential geologic and biological habitat information for validating the acoustic datasets. Underwater video is also an excellent ground-truth method, if water clarity is acceptable.
4. A simple statistical examination of the acoustic, geological and biological data allows ecologically-relevant patterns to emerge.
5. The proposed NOAA CMECS classification standard (Madden et al. 2009) while useful, has limitations when attempting to map subtle but potentially important changes in habitat. A proposed scheme aimed at helping users achieve the goals of ecosystem-based management (Guarinello et al. 2010) incorporates detail relevant to both ecological patterns and management decisions, and is flexible and adaptable to new information and growing datasets.

Recommendations

1. A suite of instruments (acoustics plus ground-truthing) should be utilized to delineate and confirm shallow water habitat patterns.
2. If a continuous, full-coverage biological habitat map is desired, the study must include an adequate number of ground-truth stations in order to make statistical extrapolation reliable.
3. An extension of the CMECS III classification standard should be used to do the detailed habitat classification and mapping necessary in shallow water and required for making informed management decisions.
4. Either the BayMap protocol used in this study, or other similar approaches, are cost-effective habitat mapping protocols that will produce detailed maps. Tables 9-11 may be used as tools for planning surveys and estimating survey costs over a range of coastal environments. Given these considerations, a detailed study of an area ~2 meters deep and 1500 acres in size would require 6.4 acoustic survey days, 14 ground-truth survey days, and 19 data processing days for a cost of ~$108,000. If you include $22,000 for laboratory analyses and report writing, then the overall study would cost $130,000 (~$87/acre or ~$55,500/square mile).

Table 9. Ground-truth survey planning and costs (sample acquisition only). Day rate does not include survey vessel and three crew ($3665/day).

	Grab samples	Sediment profile imagery (SPI)	Underwater video	
Cost per day	$200	$350	$250	
Number of days required	0.5	0.5	0.5	Low density
	3	3	3	High density

Table 10. Acoustic, ground-truthing and mapping data processing costs.

	Acoustic data processing	Ground-truthing		Laboratory analyses/report prep	
Cost per day	$600-800	$600-800		N/A	
Number of days required	3	0.5 per acoustic survey day (low density)	3 per acoustic survey day (high density)	Total cost: $10,000 - $15,000 (low density)	Total cost: $30,000 - $40,000 (high density)
Products	full side scan sonar mosaic, bathymetry surface, subbottom geology map	Grab samples, SPI images, underwater video transects		Grain size, organic content benthic biology, SPI analysis, video analysis, Final interpretation and report	

Table 11. Acoustic (interferometric sonar - side scan + bathymetry) survey planning and costs. Costs include day rate of $4665/day for survey boat, crew of three, and survey instrumentation.

	Water depth (m)									
Acres	1	2	3	4	5	10	20	30	40	50
	Total number of survey days to achieve 100% bathymetry & side scan coverage									
500	4.3	2.1	1.4	1.1	0.9	0.4	0.2	0.1	0.1	0.1
1000	8.5	4.3	2.8	2.1	1.7	0.9	0.4	0.3	0.2	0.2
1500	12.8	6.4	4.3	3.2	2.6	1.3	0.6	0.4	0.3	0.3
2000	17.1	8.5	5.7	4.3	3.4	1.7	0.9	0.6	0.4	0.3
2500	21.3	10.7	7.1	5.3	4.3	2.1	1.1	0.7	0.5	0.4
5000	42.7	21.3	14.2	10.7	8.5	4.3	2.1	1.4	1.1	0.9
7500	64.0	32.0	21.3	16.0	12.8	6.4	3.2	2.1	1.6	1.3
10000	85.4	42.7	28.5	21.3	17.1	8.5	4.3	2.8	2.1	1.7
15000	128.0	64.0	42.7	32.0	25.6	12.8	6.4	4.3	3.2	2.6
25000	213.4	106.7	71.1	53.4	42.7	21.3	10.7	7.1	5.3	4.3
50000		213.4	142.3	106.7	85.4	42.7	21.3	14.2	10.7	8.5
75000		320.1	213.4	160.1	128.0	64.0	32.0	21.3	16.0	12.8
100000			284.5	213.4	170.7	85.4	42.7	28.5	21.3	17.1
250000						213.4	106.7	71.1	53.4	42.7
500000							213.4	142.3	106.7	85.4
750000							320.1	213.4	160.1	128.0
1000000								284.5	213.4	170.7
	Estimated survey cost (instrumentation, staff, vessel)									
500	$20,060	$10,030	$6,687	$5,015	$4,700	$4,700	$4,700	$4,700	$4,700	$4,700
1000	$40,121	$20,060	$13,374	$10,030	$8,024	$4,700	$4,700	$4,700	$4,700	$4,700
1500	$60,181	$30,091	$20,060	$15,045	$12,036	$6,018	$4,700	$4,700	$4,700	$4,700
2000	$80,242	$40,121	$26,747	$20,060	$16,048	$8,024	$4,700	$4,700	$4,700	$4,700
2500	$100,302	$50,151	$33,434	$25,075	$20,060	$10,030	$5,015	$4,700	$4,700	$4,700
5000	$200,604	$100,302	$66,868	$50,151	$40,121	$20,060	$10,030	$6,687	$5,015	$4,700
7500	$300,906	$150,453	$100,302	$75,226	$60,181	$30,091	$15,045	$10,030	$7,523	$6,018
10000	$401,208	$200,604	$133,736	$100,302	$80,242	$40,121	$20,060	$13,374	$10,030	$8,024
15000	$601,812	$300,906	$200,604	$150,453	$120,362	$60,181	$30,091	$20,060	$15,045	$12,036
25000	$1,003,020	$501,510	$334,340	$250,755	$200,604	$100,302	$50,151	$33,434	$25,075	$20,060
50000		$1,003,020	$668,680	$501,510	$401,208	$200,604	$100,302	$66,868	$50,151	$40,121
75000		$1,504,530	$1,003,020	$752,265	$601,812	$300,906	$150,453	$100,302	$75,226	$60,181
100000			$1,337,360	$1,003,020	$802,416	$401,208	$200,604	$133,736	$100,302	$80,242
250000						$1,003,020	$501,510	$334,340	$250,755	$200,604
500000							$1,003,020	$668,680	$501,510	$401,208
750000							$1,504,530	$1,003,020	$752,265	$601,812
1000000								$1,337,360	$1,003,020	$802,416

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Appendix A

GeoSwath Plus Demonstration Survey, Great South Bay, NY.

Carried out with the University of Rhode Island and GeoAcoustics Ltd.

Data collected August 2006

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Introduction

The Great South Bay is a shallow lagoon approximately 45 miles (72 km) long that forms a large natural harbor on the southern side of Long Island, New York. It is protected from the Atlantic Ocean to the South East by Fire Island, a barrier island approximately 30 miles (48 km) long. The bay opens to the Atlantic via a narrow inlet at the western tip of Fire Island.

On Thursday 17th August 2006 a trial survey was carried out near the middle of Great South Bay (40º40N, 73º00W) using a 250kHz GeoSwath Plus wide swath sonar from GeoAcoustics Ltd. The trial was attended by personnel from the Graduate School of Oceanography, University of Rhode Island, led by Professor John W King. The sonar was mounted on a temporary mount over the side of the University's trailerable shallow water survey platform, with the transducers mounted about 45cm under the waterline. Mobilisation and operational base was at Patchogue, NY. The survey data was subsequently processed using GeoSwath Plus and GeoTexture software to produce the images seen in this report.

Two areas were covered in the survey:

Area 1: 1km x 730m, mostly 2m-3m deep. This demonstrated 100% bathymetry and side scan coverage with 40m line spacing. Twenty-one lines of 1km each were run, plus one cross line, in 3 hours (survey speed of 3 to 4kts).

Area 2: 950m x 300m, a flat area 0.85m deep (0.4m clearance under the transducers). This survey demonstrated lower coverage techniques, achieving 25% bathymetry coverage and 100% side scan coverage with 50m line spacing. Eight lines of 950m each were run in 1h 5min.

The trial demonstrated the GeoSwath's wide swath productivity in very shallow waters, and its ability to collect co-registered side scan (amplitude) data along with the bathymetry. This report describes the GeoSwath technology, the survey equipment used and the data processing methods, and presents the survey results from the two areas.

Equipment Description

The vessel used was the University of Rhode Island trailerable pontoon launch, a 4m long platform often used for shallow survey work by the University (Figure A.1). The GeoSwath sonar was mounted using a side pole mount bolted to a deck plate on the starboard side of the launch. The installation and all offset measurements for the sonar, positioning system and heading reference unit were done the day before the survey.

Figure A.1: The survey launch being mobilised in Patchogue marina. The standard GeoAcoustics pole mount bracket was bolted on the starboard side of the launch, with the transducers set at 45cm below the waterline, just below the draft of the centre keel. The 2 GPS aerials of the POS-MV can be seen on top of the pole in the upper left of the image.

The following peripherals were used:

- RTK GPS and base station, providing RTCM corrections to the POS-MV
- Applanix POS-MV v4 attitude and heading reference, with the inertial measurement unit (IMU) mounted on the sonar head (Figure A.2)
- Tritech PA200 Altimeter, on the sonar head
- Valeport Mini Sound Velocity Sensor (SVS), on the sonar head
- A Sound Velocity Profiler (SVP) was not used as the shallow bay will have well mixed waters, so the sound velocity at the head could be used.
- Tide data was obtained from a tide gauge deployed in Patchogue marina – tidal variation was about 30cm over the survey period.

Calibration

The calibration was carried out using overlap data from area 1. Ideally calibration can be done from 4 survey lines over a flat area (for roll) and across a slope or channel (for latency, pitch and yaw). In this calibration area the depth was shallow and fairly constant, so no area suitable for the automated calibration of latency, pitch and yaw was available. This calibration had to be completed by manual methods using small features seen in the test area. Navigation latency calibrated at 0.000s as expected, since 1PPS timing was used to synchronise the GeoSwath with the GPS clock.

The GeoSwath Sonar Technology

The GeoSwath Plus is a phase measuring bathymetric sonar (PMBS, sometimes called "interferometric multibeam"). The GeoSwath sends out a short pulse of sound (~10cm, user selectable) at 250kHz (125kHz and 500kHz versions are also available). This pulse is very wide across track and narrow (~0.9°) along track. The GeoSwath Plus uses phase measurement electronics to determine the direction of the returning sound, with an angle resolution of a fraction of a degree (about 0.03° at boresight). Range is found from the return time, and is measured with centimetric accuracy. This high resolution in range and angle means there are no footprint problems at shallow incident angles and the data density stays high out to the swath edge. The GeoSwath field of view is very wide - indeed these sonars can survey a canal up to the waterline in one pass. On a flat, shallow seafloor this allows a very wide swath, only limited by the weakness of the sound scattered back at small angles and by the absorption and scattering in the water column.

Table A.1: Calibration results:

Parameter	Value	Comments
Latency	0.000s	1PPS synchronisation of GeoSwath and GPS clocks was used.
Port Roll	0.30º	POS dynamic accuracy ~ 0.02º in roll (~2cm at 40m)
Starboard Roll	0.05°	POS dynamic accuracy ~ 0.02º in roll (~2cm at 40m)
Pitch	0.0º	Due to shallow depth (3m max) and positioning accuracy (±0.2m) pitch is not important to better than ±2° (~10cm position error)
Yaw	0.0º	Beamwidth 0.9º so accuracy better than 0.5º not required.
Attitude Latency	0.025s	Typical for POS data delivered via serial string in this configuration

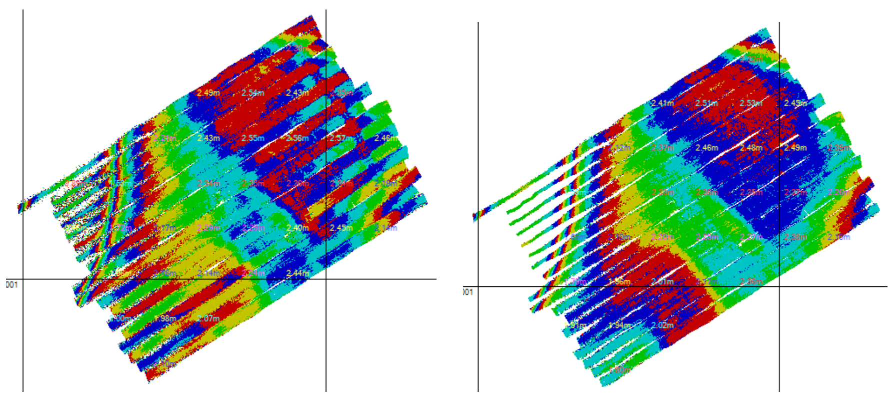

Figure A.3:Survey data from area 1 before (left) and after (right) application of calibration and tide data. Colour changes are every 10cm.

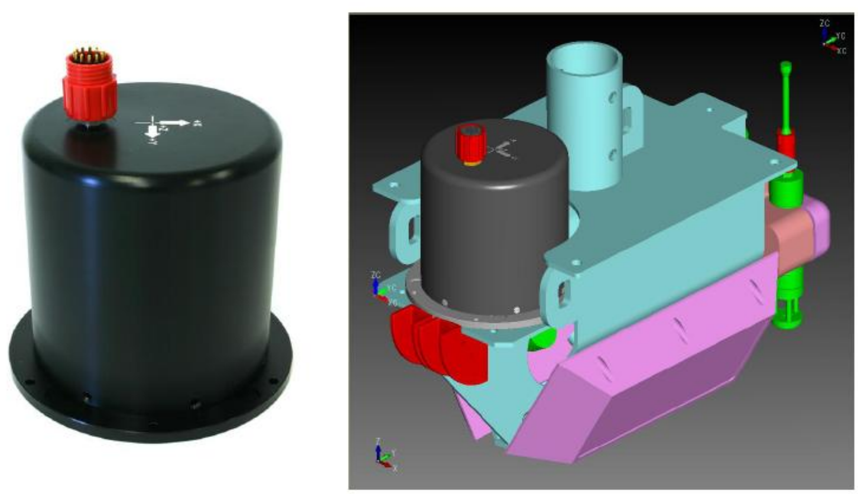

Figure A.2: The POS-MV subsea hosing for the IMU (left), and schematic showing how it is mounted on the GeoSwath transducer head. Highlighted in pink are the port and starboard transducers (mounted facing 30º down from horizontal), in green is the sound velocity sensor. For scale, the IMU housing is 20cm diameter.

The GeoSwath is compact and robust, designed for pole mounting and deployment on survey vessels of opportunity. The system field of view in the usual 2 transducer configuration is over 250°. The GeoSwath collects both bathymetry and co-registered side-scan data simultaneously, which helps with feature identification, habitat mapping, and feature detection confidence.

While the standard deviation of the raw soundings can be high, the high sounding density of the GeoSwath gives many data points per square metre, resulting in very accurate bin mean depths. The precision of the mean depth in a bin (standard error of the mean) is given by the standard deviation of the soundings in the bin divided by the square root of the number of soundings. This precision can be illustrated by the self-consistency of depths in bins from a flat area of seafloor – variations of 1cm - 2cm are typical. The high sounding density of the GeoSwath also allows the sounding distribution in individual bins to be inspected and the standard deviation of the soundings in the bin to be measured.

Data Collection

Standard survey ‘lawnmower’ patterns were run over the two survey areas, with a cross check line run over the eastern end of area 1. This equally-spaced pattern works well for wide coverage, but is not ideal for small object detection and identification in the side scan. This is because directly under the vessel there will be no acoustic shadow behind an object. A ‘side scan search’ survey pattern used by the Navy consists of lines with 120% overlap on one side and 20% on the other: this means pairs of lines are run, each line looking under the centreline of the other line in the pair. This will result in every object having a shadow, aiding identification, but productivity is reduced to about 70%. In this case the bottom type was of more interest in the side scan image, so lines were run for maximum productivity.

Data Processing

The GeoSwath Plus is supplied with a complete set of software for data collection, calibration, filtering, generation of digital elevation models (DEMs) and side scan mosaics. Data quality control and data visualisation tools are an important part of the package.

In data processing the raw swath data was filtered to remove outliers, sound velocity corrections were applied and navigation data was checked and edited using the GeoSwath Plus software. The calibration parameters were applied to the swath data, and tide and SVP files were applied. This gave georeferenced, calibrated data files on a line-by-line basis. All this happens in an automated (but user accessible) way inside the GeoSwath Plus software system.

Once the data has been collected the GeoSwath plus software can be used to inspect and edit the navigation, attitude and heading data. Data processing consists of several steps

Figure A.4: Survey equipment deck units: the POS-MV (orange) is on top of the GeoSwath, with the screen, keyboard and mouse on top of the POS.

Figure A.5: On Survey with the GeoSwath. Note the pole mount starboard amidships. Weather and sea state conditions were similar to this for the whole survey.

Figure A.6: Bathymetry cross profile and side scan waterfall being monitored during the survey.

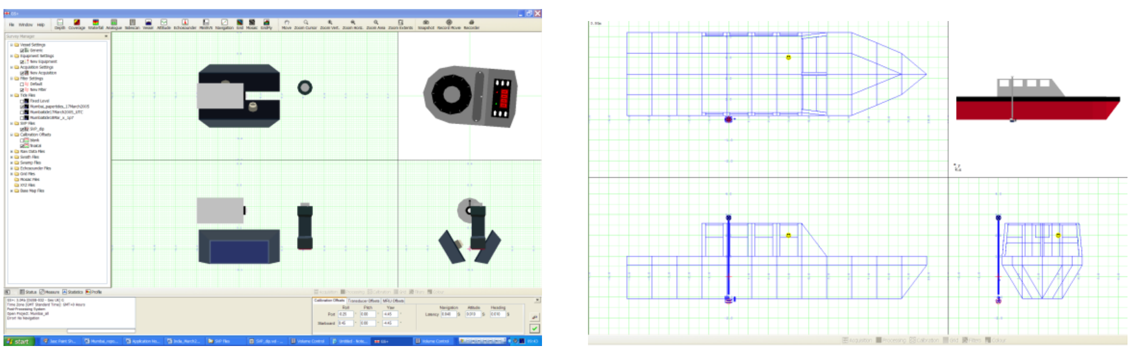

Figure A.7: Calibration Offsets screen (left) and Vessel Editor (right) in GeoSwath Plus

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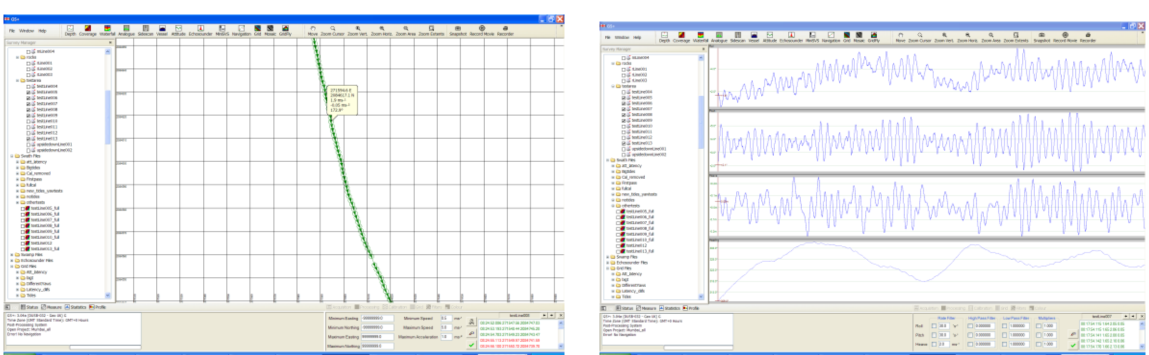

Figure A.8: Navigation Editor (Left) and Attitude Editor (right) in GeoSwath Plus from raw data to final chart. These are shown in outline in Figure A.9.

Other processing paths are available via third party software, for example the GeoSwath data can be interfaced directly to Hypack in real time, and recorded in Hypack native formats (HSX). Another possible route is via the GeoAcoustics CBF format into the NOAA GSF format, and then into Fledermaus software for processing using the CUBE algorithms.

The first step of processing is the merging of data from the ancillaries to give a georeferenced dataset. Processing then consist of rejection of outliers followed by statistical combination of data into bins.

The gridder in GeoSwath Plus was used to bin the data in 1m grids for DTM generation. A 1m bin size gives many soundings per bin when using the GeoSwath, increasing the depth accuracy of the bin and the depth confidence of the binned data. As the positioning system accuracy was better than ±0.1m smaller bins could be used, and this gave better definition of small features where required. This small bin size could give an unacceptably low data density at nadir, so is not always ideal unless the survey is run with pairs of lines (overlapping centre to centre) to ensure complete high density coverage.

After gridding, the DEM was inspected, the images in this report were generated, and XYZ files were exported using the GeoSwath Plus software.

Swath Width Achievable in Shallow Waters

The waters in Great South Bay are particularly shallow, with the deepest areas seen in the trial survey at 3m deep. In such shallow waters the achievable swath width for bathymetry is limited by the scattering properties of the bottom: as the incident angle of the sound gets small, most of the sound ends up scattering away from the source rather than back to the receivers. The result of this is a higher signal-to-noise ratio (S/N) at the outer edges of the swath.

This poor S/N will appear as a ‘spreading’ of the soundings around the seabed. The GeoSwath collects data at a high density, up to 50 soundings per meter slant range (= nearly 50 soundings per meter horizontal range at low angles). This allows the depth to be determined wit h some accuracy by binning the data, even though the standard deviation seen in the raw data might be high. As an example, if the raw data S/N results in a standard deviation of depths of 35cm, then a data density of 25 points per meter across track and 2 pings per 1m bin along track will result in a bin mean with a standard error of 5cm.

In the Great South Bat data accuracies in bathymetry were below 5cm for swath widths up to about 10m even in the shallowest areas (about 20cm under the transducers), and

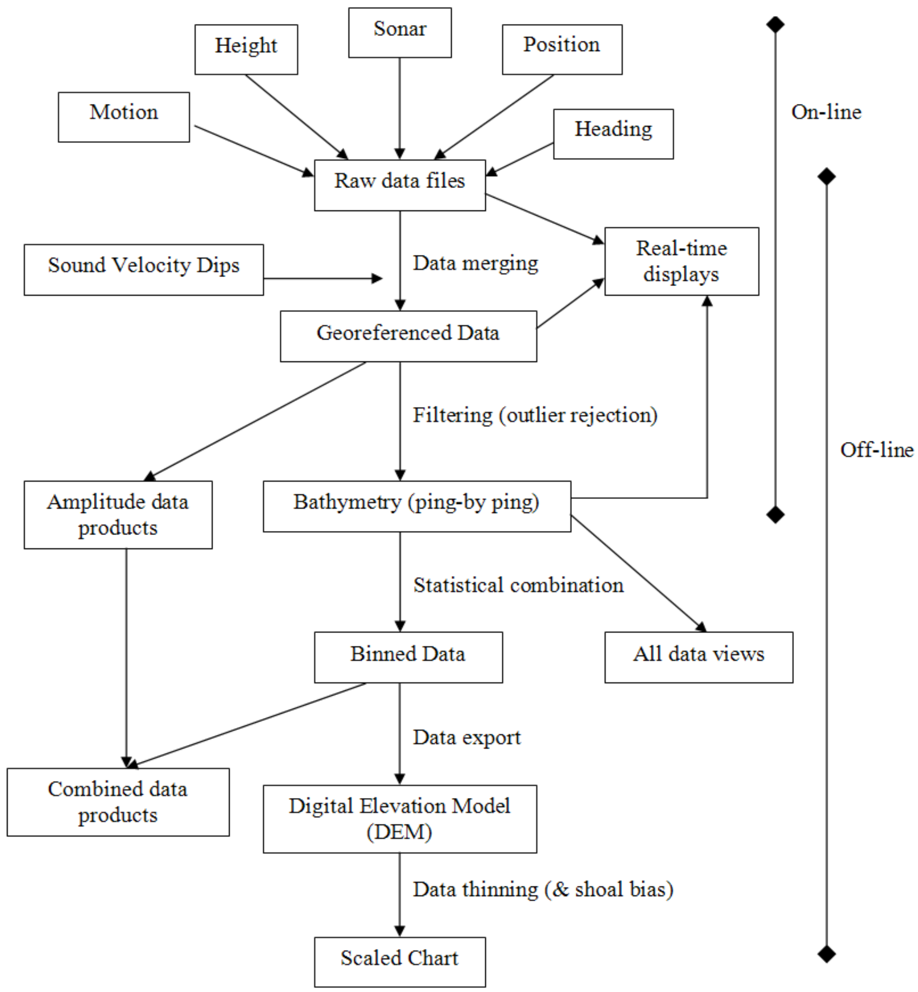

Figure A.9: The data input and processing steps taken in analysing a GeoSwath data set. All these processes and visualisations are available within the GeoSwath Plus Software.

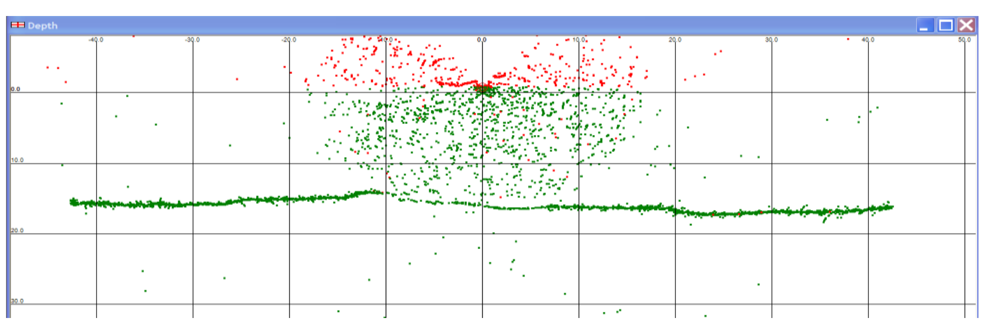

Figure A.10: The full data from one ping on the main survey area , showing noise and outliers.

about 40m in areas 2m or more deep. This is shown in Figures A.12 – A.15.

The side scan processing can use a much wider swath than the bathymetry. This is because bathymetry measurement relies on the measuring the phase of the returning sonar signal, so require S/N of about 30dB or more. Side scan amplitude images give useful information at much lower S/N: even with a S/N of -1dB the human vision system can pick out useful linear features. Figures A.16 – A.17 are examples of the side scan swath from the two lines above, showing drag marks and bottom contrast over a wider swath.

Side Scan Processing

The side scan data was processed using GeoSwath postprocessing tools and 'swamp' (swath amplitude) files created for each line. These swamp files were loaded into GeoTexture, a separate processing package from GeoAcoustics Ltd. All side scan images in this report were generated from GeoTexture normalised swamp files.

GeoTexture contains tools for normalising the swath images using the beampattern of the transmit and receive transducers, and the angular response characteristics of the seafloor. This is only possible with GeoSwath data, as that data contains co-registered bathymetry and amplitude information. GeoTexture can be applied to xtf side-scan data, but has to make the assumption that the towfish was level and the seafloor was flat – if these assumptions are wrong this can result in image artefacts.

With GeoSwath data the side scan mosaic images created can approach the ideal of 'seamless side scan' where all the image contrast comes from variation in the seafloor. In the survey in Great South Bay there are some artefacts in the images that remain: these are from sonar reflections off the keel of the hulls of the survey craft (the stripes along the centres of the tracks in the side scan images). This could be prevented by having a bow pole mount over the front of the vessel, so the hulls are not in the field of view.

An additional capability in GeoTexture is the texture mapping of the normalised image. This is done from a training texture set chosen from parts of the image. The user selects small areas of distinct texture as the training set, then GeoTexture can segment the whole side scan mosaic into areas that match training set. These texture mapped images can be exported, with each texture as a different colour. This is allows easy export of different layers into a GIS package. When combined with directed groundtruth samples and the bathymetry map GeoTexture allows full coverage bottom habitat classification maps. Some examples of texture mapped images were created for this report, however the scope of the report did not allow for a complete GeoTexture processing of all the data and subsequent comparison with groundtruth bottom samples.

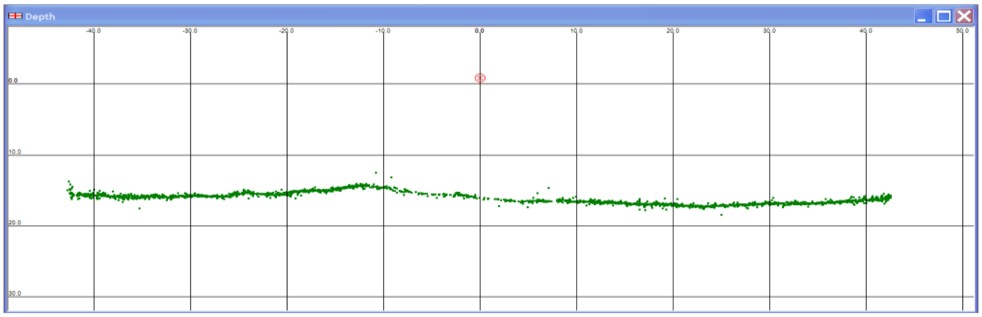

Figure A.11: Filtered data from the above ping after rejection of low amplitude data and outliers.

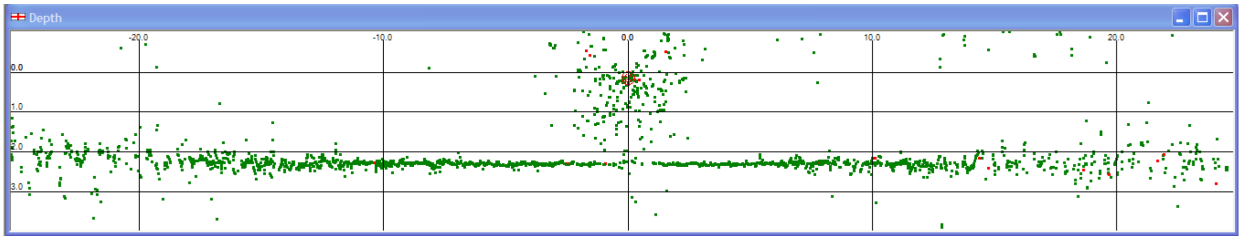

Figure A.12: Swath profile from area 1 (single ping from each side shown). Water depth is about 2.5m (2.1m under the transducers). When processing the swath was limited to 20m each side: the spread of data at the swath edges is compensated by the high data density which allows accurate means in 1m bins.

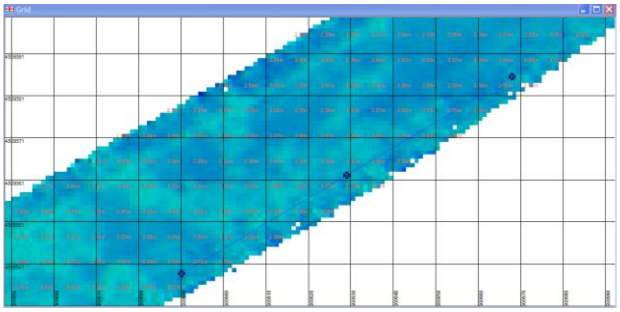

Figure A.13: Gridded swath from the above line in area 1: the blue line shows the location of the profile shown in figure A.14. The vessel was heading North East on this line: the slight effect of the keel reflections can be seen in the bathymetry on the port side.

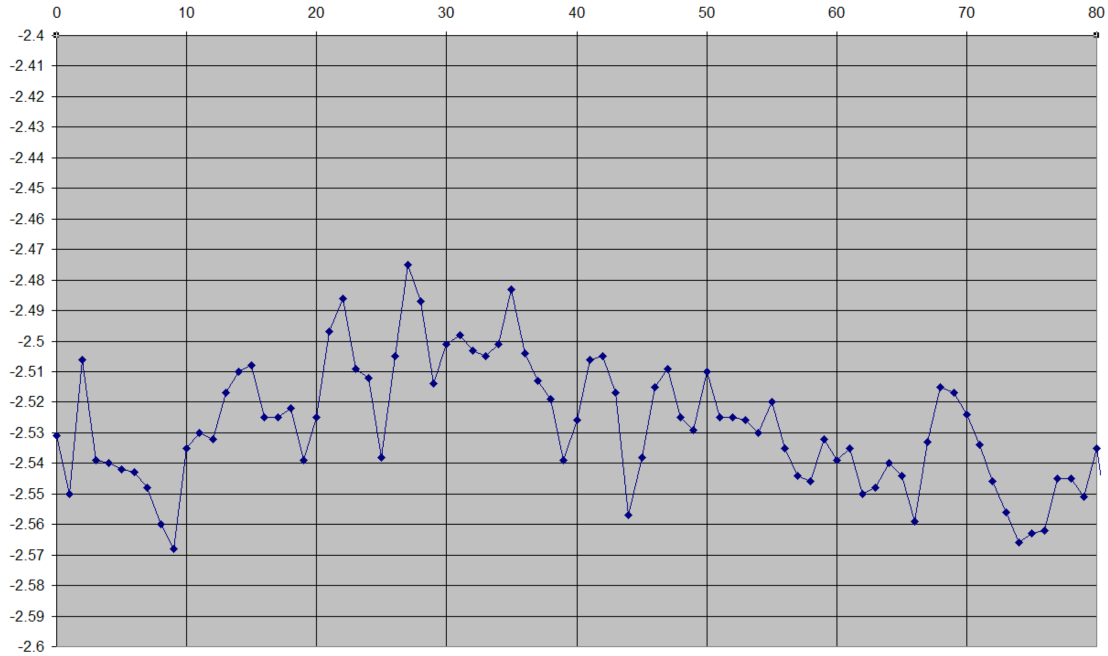

Figure A.14: Profile through the above grid: note the variation bin-bin is less than 5cm at the edge of this 40m swath (total swath width roughly 20 times the water depth under the transducer head).

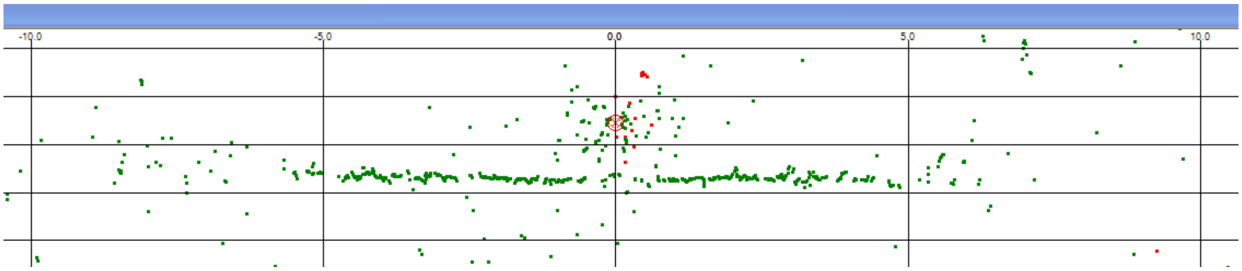

Figure A.15: Swath profile (single ping shown) from area 2, about 85cm deep (40cm under the transducers). Here there is only about 5m per side useable bathymetry.

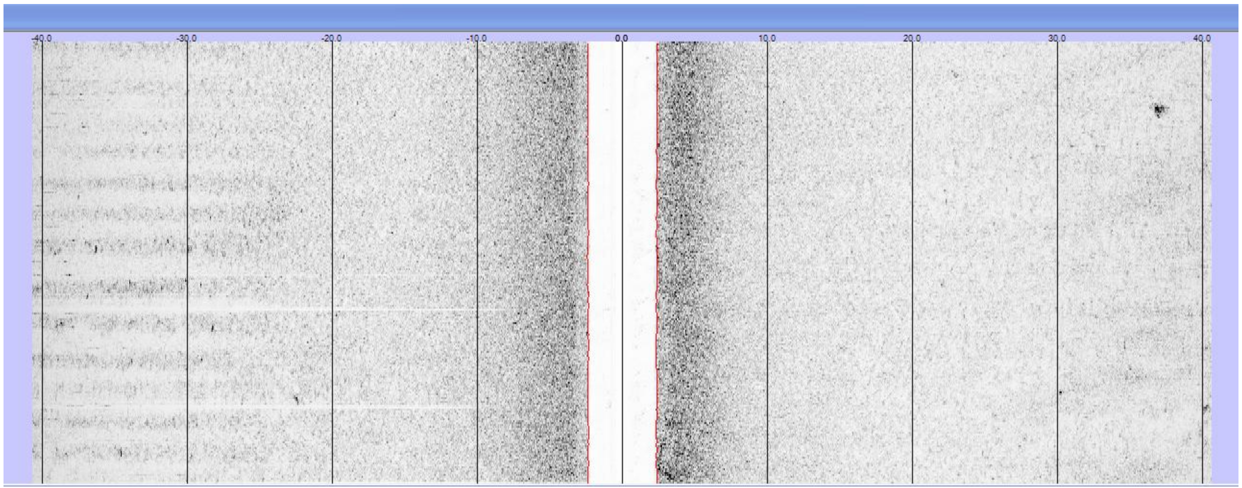

Figure A.16:Side scan waterfall from a single swath in area 1 (2m water depth, plotted in slant range). The difference between the port and starboard sides can be clearly seen.

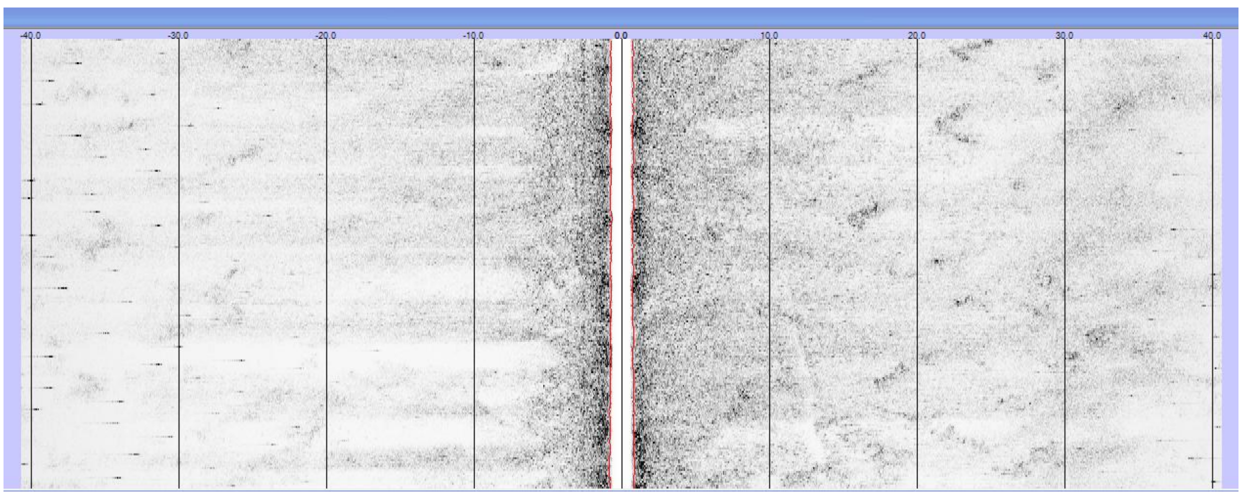

Figure A.17: Side scan waterfall from a single swath in area 2 (85cm water depth, same range setting). The very dark marks at far range (more visible on port side) are interference from another boat's sonar. Again, the problems from keel reflections to port can be seen

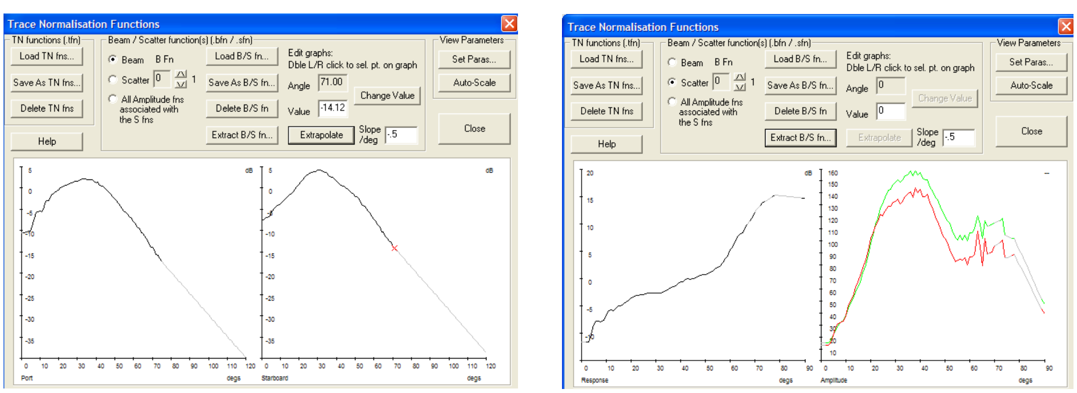

Figure A.18: GeoTexture calibrated beampattern plots (left)and measured bottom scattering properties (right) used to normalise the side scan images.

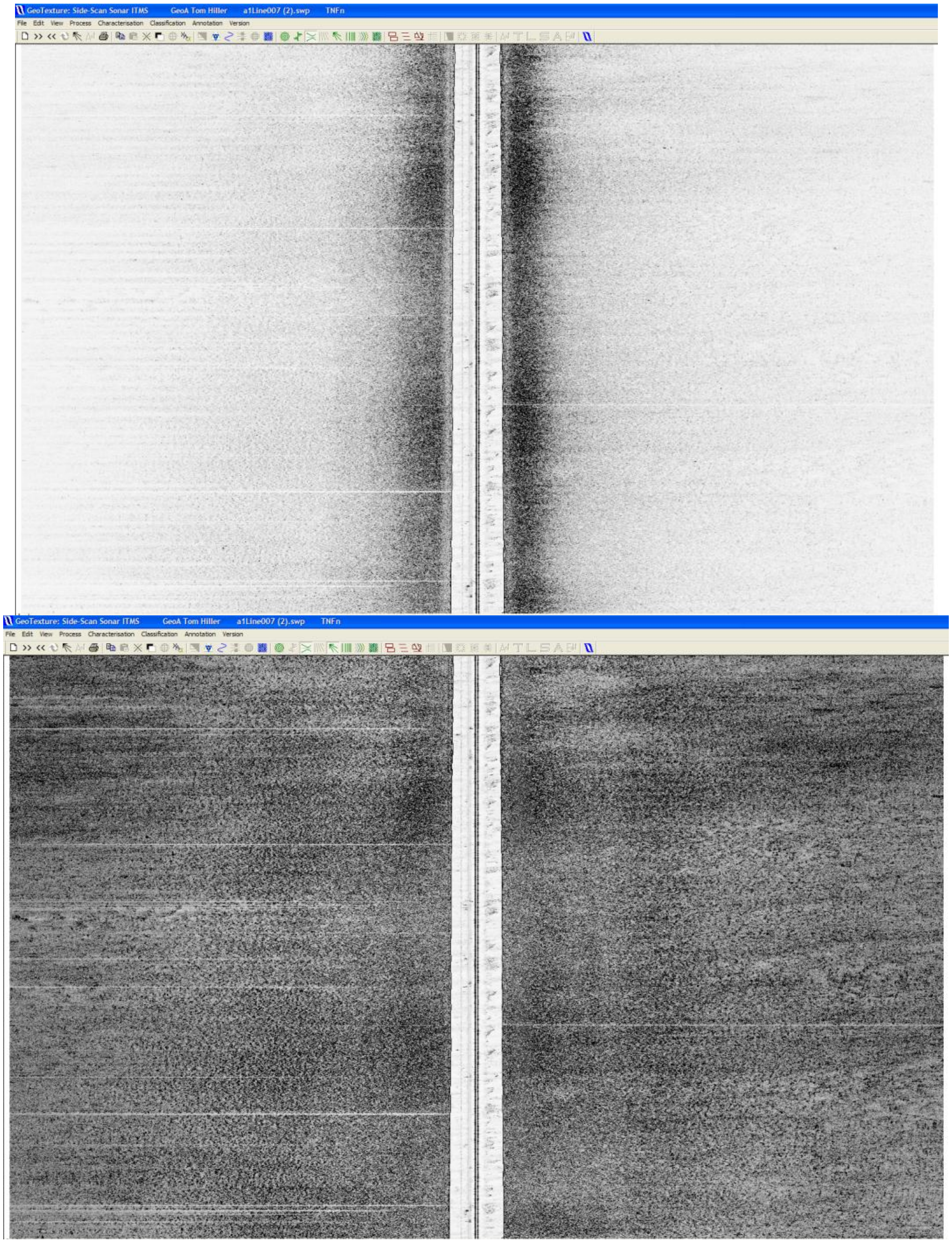

Figure A.19: A single swath of side scan data before normalisation (top) after normalisation (bottom). Note how the subtle variations in the seafloor are enhanced.

Data Deliverables

The electronic data from this trial survey was delivered to the University of Rhode Island as (x,y,z) and (x,y,a) ASCII grids and as georeferenced image files (tiff image & tfw world file). There are also standard output formats that can be imported into third party software such as Fledermaus, Caris HIPS, Hypack, or Surfer (by Golden Software) for further processing.

Examples of recent large area GeoSwath surveys include:

- A government funded shallow mapping project on the south UK coast (1m depth contour to 1km further out to sea). GeoSwath data was transferred to Fledermaus as GSF (Generic Sensor Format) files, and processed in Fledermaus using the CUBE algorithms from the CCOM/JHC NOAA centre at the University of New Hampshire.

- A six month NOAA contract for a debris survey of Lake Bourgne near New Orleans, where Hurricane Katrina made landfall. This survey was carried out by SAIC Inc. of Newport RI.

- United States Army Corps of Engineers at the Field Research Facility in Duck, NC, operated a GeoSwath with GeoTexture processing for a shallow water survey in the Chesapeake bay. The objective of the survey was environmental mapping to help guide where bridge piers could be placed in order to limit the environmental impact of a new crossing.

- The New South Wales Department of Environment & Conservation (NSW DEC) have been using a 125 kHz GeoAcoustics GeoSwath and GeoTexture for habitat mapping within the state's network of Marine Protected Areas. The maps produced have proved invaluable in the planning process for two new parks announced last year and that come into effect during the first half of 2007. The GeoSwath system has been used extensively at Great Lakes Marine Park, a site where the endangered Grey Nurse Shark (Carcharias taurus) gathers. The GeoSwath data collected by the NSW DEC has contributed significantly to the inclusion of many reefs to the south and east of the island within Sanctuary and/or Habitat Protection zones for the new Marine Park.

- Use of the GeoSwath equipment continues in Australia with a new program due to commence in July 2007 and run for the next 2 years. This project involves habitat mapping for the state's coastal Catchment Management Authorities, focusing on sections of the NSW coast to help in the understanding of the biodiversity associated with shallow (<80m) subtidal reefs in coastal waters.

- A remotely operated vehicle (ROV) mounted GeoSwath was used for identifying cold-water coral colonies in Trondheim Fjord, Norway. At 60m deep the Tautra ridge in Trondheim Fjord is home to world’s shallowest known cold-water coral reef. The GeoSwath co-registered side-scan and bathymetric data allowed maps of the coral extents to be made on the ROV control vessel in real time. These observations were then used to plan video transects of selected sites which confirmed the presence of the corals.

Great South Bay Survey Results

The survey run lines for area 1 (to the north) and area 2 (to the south) are shown in Figure A.20. The graticule spacing in the image is 1km.

The plotted run lines are derived from the recorded navigation data stored in the RDF, which includes the GGA GPS string sent every second. An example taken from one of the lines is shown below:

$GPGGA,175235.00,4043.0101294,N,07259.8664832,W,2,09,0.9,4.77,M,-34.49,M,4.6,0007*72
$GPGGA,175236.00,4043.0103423,N,07259.8655967,W,2,09,0.9,4.76,M,-34.49,M,4.4,0007*79
$GPGGA,175237.00,4043.0105702,N,07259.8648163,W,2,09,0.9,4.80,M,-34.49,M,5.4,0007*76
$GPGGA,175238.00,4043.0108282,N,07259.8640375,W,2,09,0.9,4.84,M,-34.49,M,4.0,0007*75

The final bathymetry grid and side scan mosaic images from the two survey areas are shown in Figure A.21. Here you can see the greater range available form the side scan (which can cope with much lower signal to noise ratio) which results in near full coverage in both areas, while the bathymetry only shows full coverage in the deeper (2m+) area.

The details of the two survey areas are given below:

- Area 1: 1km x 730m, mostly 2m-3m deep. This demonstrated 100% bathymetry and side scan coverage with 40m line spacing. Twenty one lines of 1km each were run, plus one cross line, in 3 hours (survey speed of 3 to 4kts).

- Area 2: 950m x 300m, a flat area 0.85m deep. This survey demonstrated lower coverage techniques, achieving 25% bathymetry coverage and 90% side scan coverage with 50m line spacing. Eight lines of 950m each were run in 1h 5min.

The images on the next pages show details of the bathymetry, side scan and classified image data collected.

Note on 500kHz GeoSwath

Since completing the survey described in this report GeoAcoustics has released a 500kHz version of the GeoSwath. This has smaller transducers (half the length and height) and higher resolution (half the beamwidth and sonar pulse length). Some results from this system are shown in Figures A.29 – A.21. This version should be considered if carrying out further survey work in very shallow waters like Great South Bay. The disadvantage of the 500kHz system is reduced range (80m) compared with the 250kHz (150m).

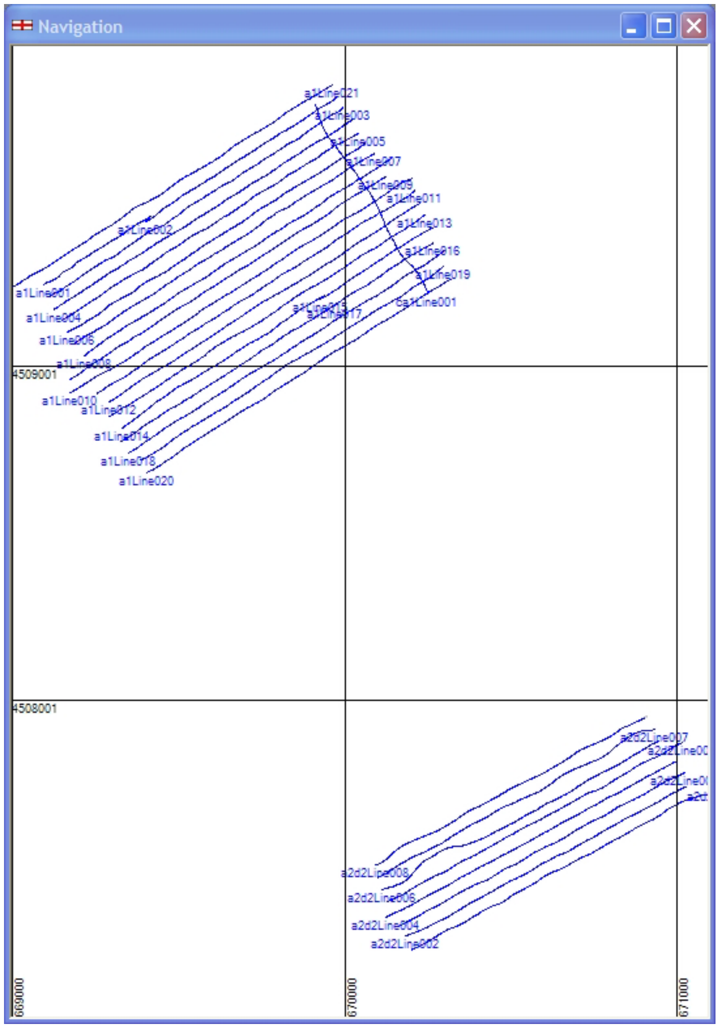

Figure A.20: Great South Bay Survey Results

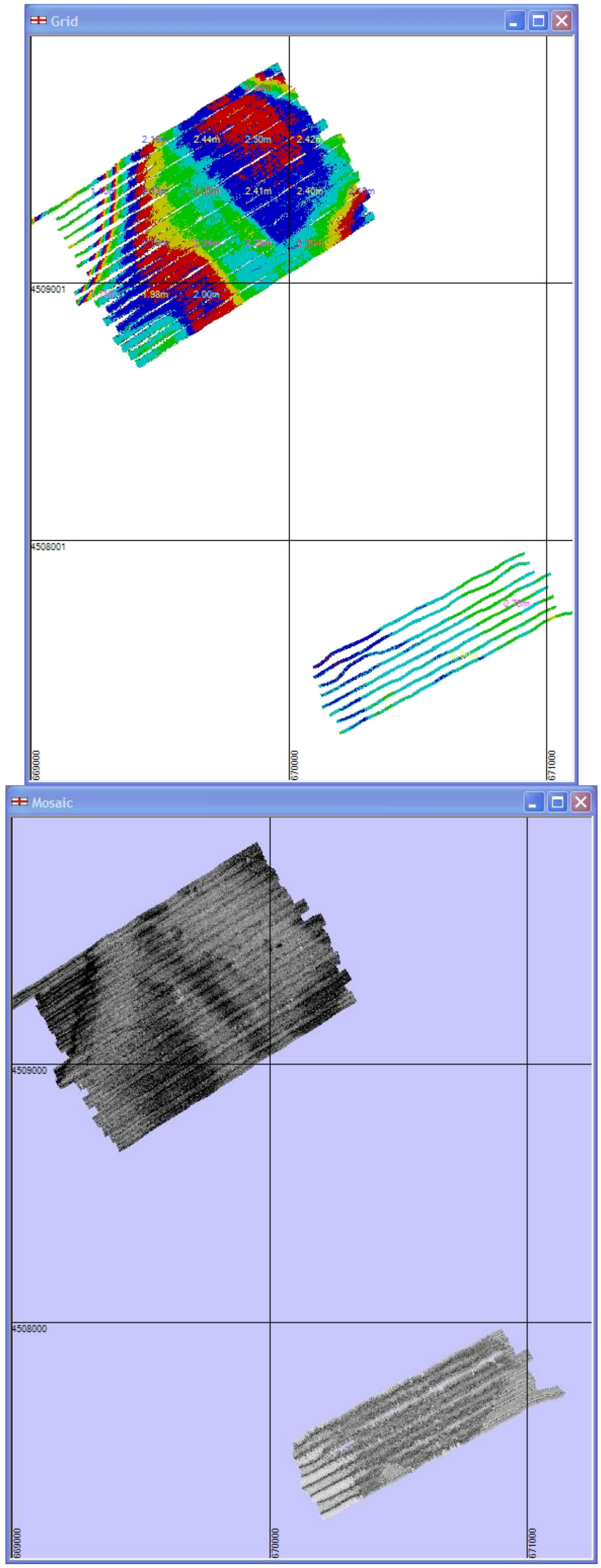

Figure A.21: Bathymetry grind and side scan mosaic images.

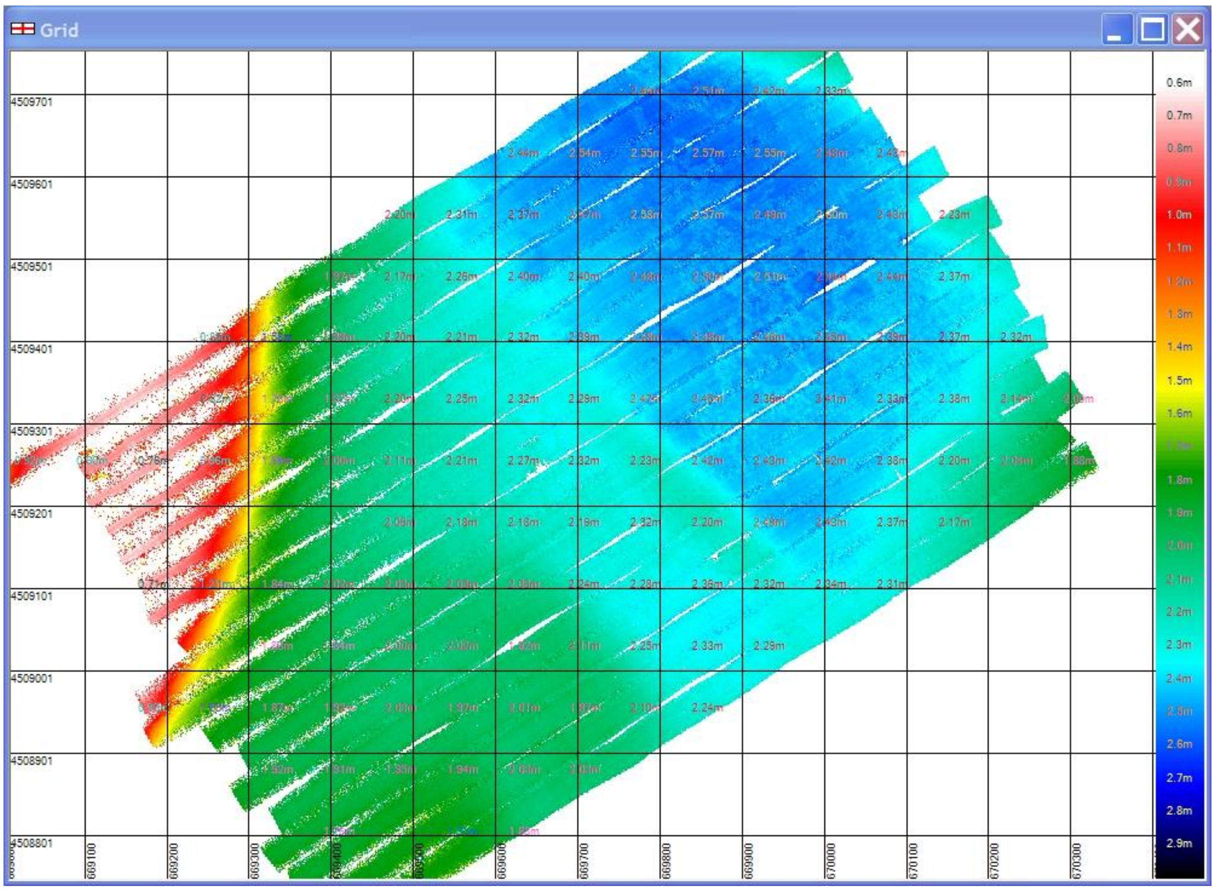

Figure A.22: Bathymetery of Area 1. Image is coloured by depth (scale on right). .

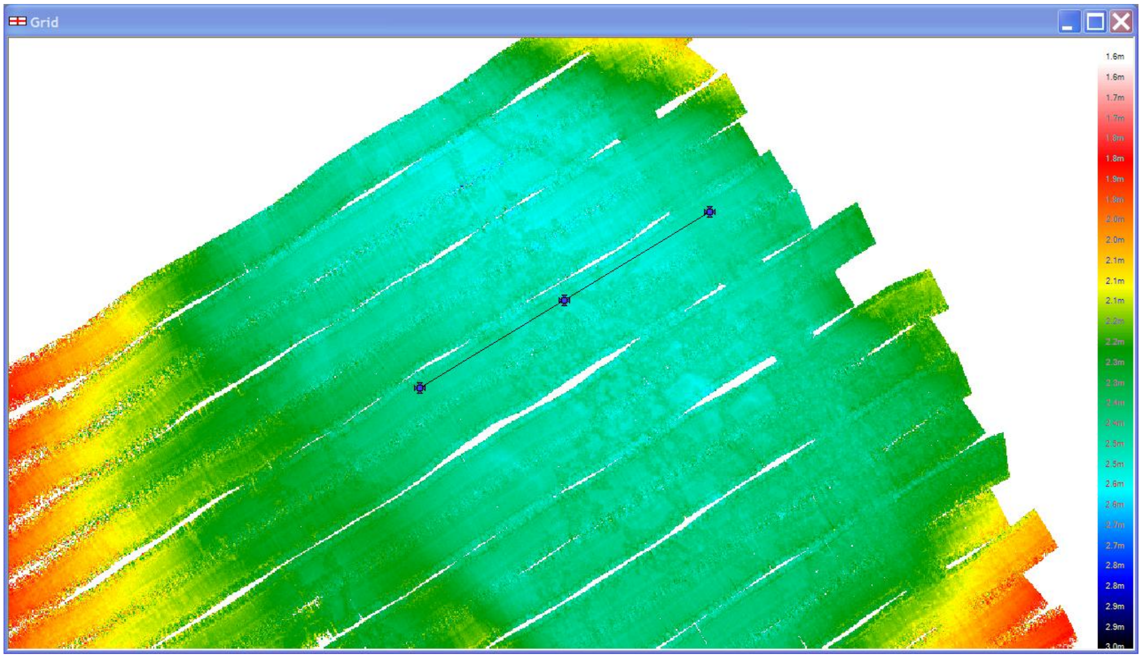

Figure A. 23: Detail of Area 1 Bathymetry, showing small colour changes attributed to the effect of eel grass beds on the sonar signal (the profile line centre is over this). Note the colour scale has been changed to emphasise this feature.

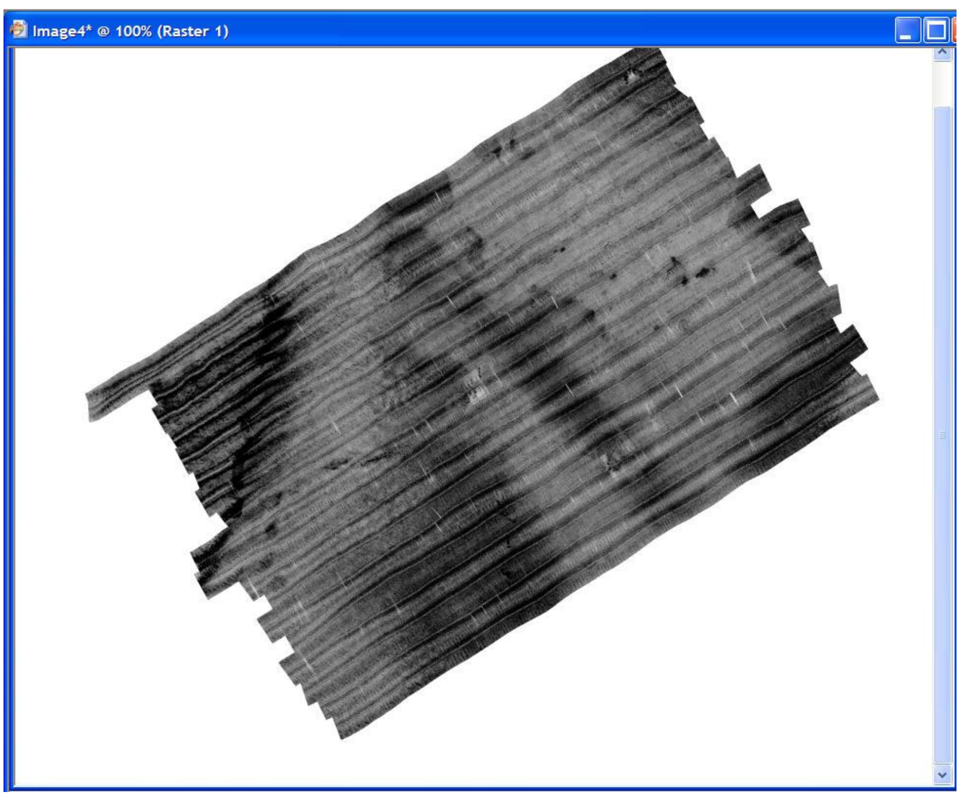

Figure A.24: Area 1 side scan image, normalised in GeoTexture. Note the problems on the port side caused by shading by the vessel keels – this could be prevented by using a bow mount.

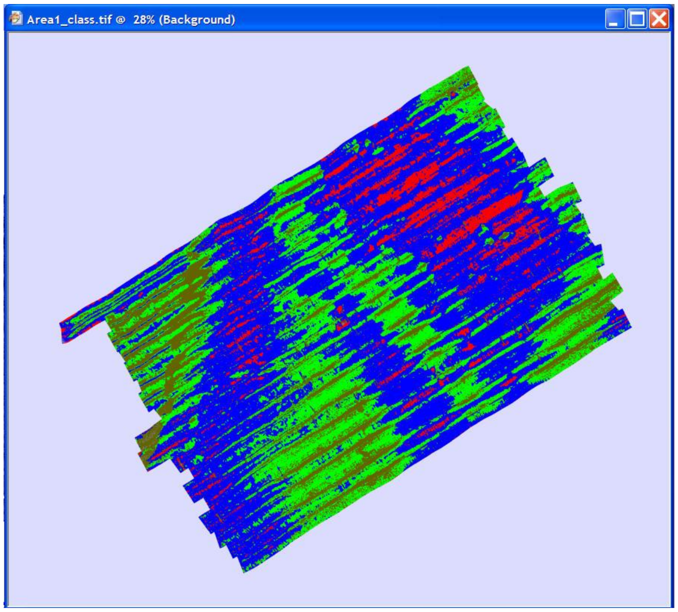

Figure A.25: Area 1 classified image, using 4 training textures extracted from the image. Note the ridge running North West to South East across the image – this can be seen in the bathymetry to be 10cm high and 100m wide.

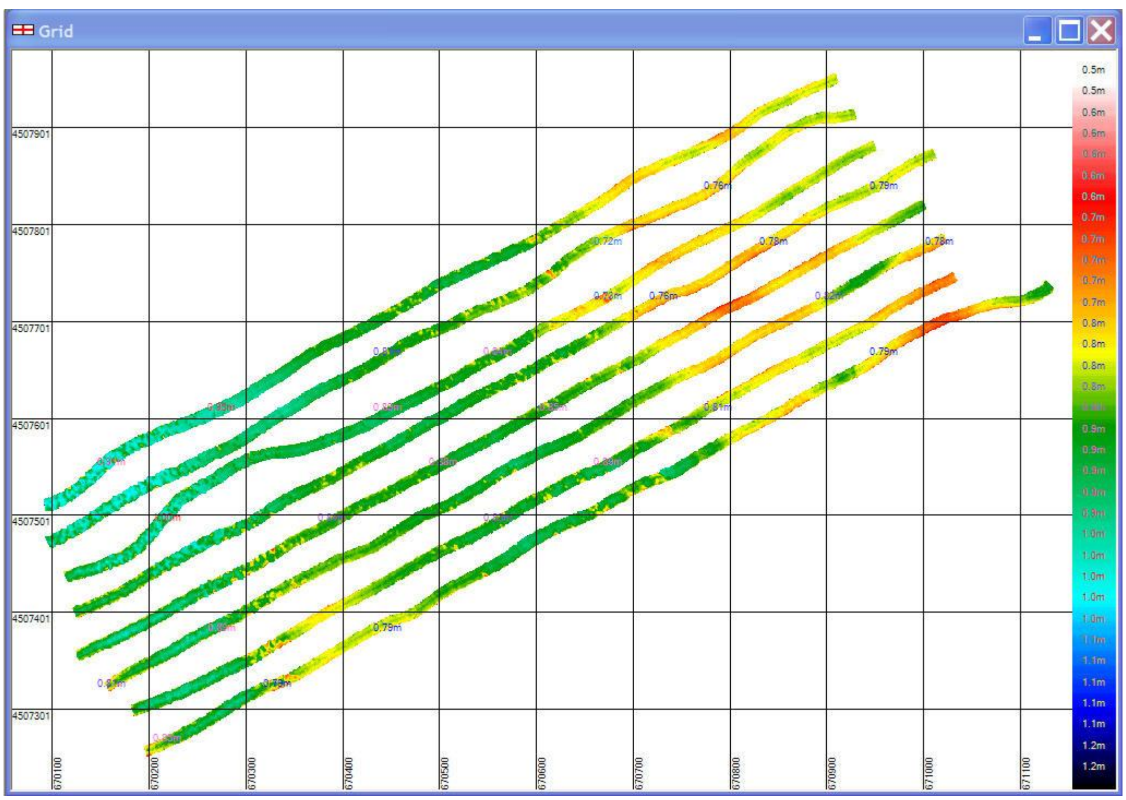

Figure A.26: Area 2 bathymetry, colour coded depth. This was surveyed at less than 100% bathymetry coverage, and shows how the wide swath can be used in this type of high productivity survey to aid interpretation of how features might 'connect' between swaths.

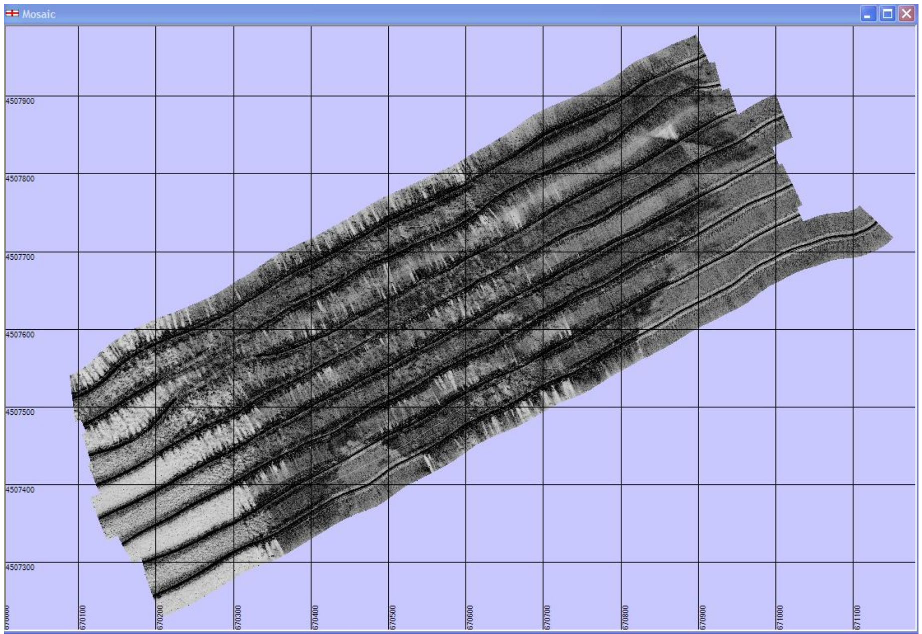

Figure A.27: Area 2 side scan, normalised in GeoTexture. Note the wider coverage possible in a side scan image than with bathymetry, even though the two are collected simultaneously.

Figure A.28: Zoomed side scan mosaic showing a features (probably small boat anchor drag marks). The features are resolved across the whole swath, and they match up between swaths. The problems seen from the keel reflections on the port side (accompanied by loss of amplitude on that side) are also obvious. These problems would not occur using a bow mount.

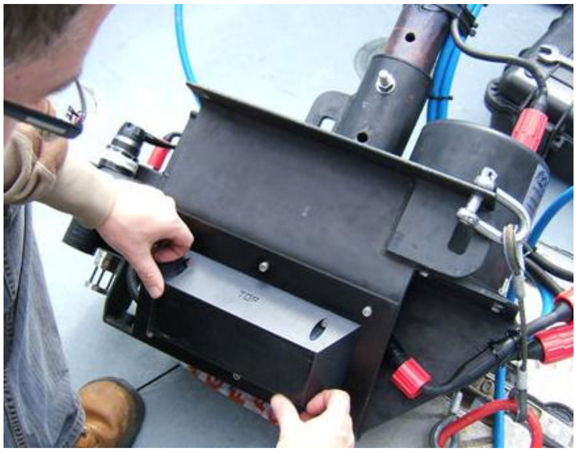
Figure A.29: 500kHz transducer on adapted 250kHz mount –compare with earlier image of the 250kHz transducers.

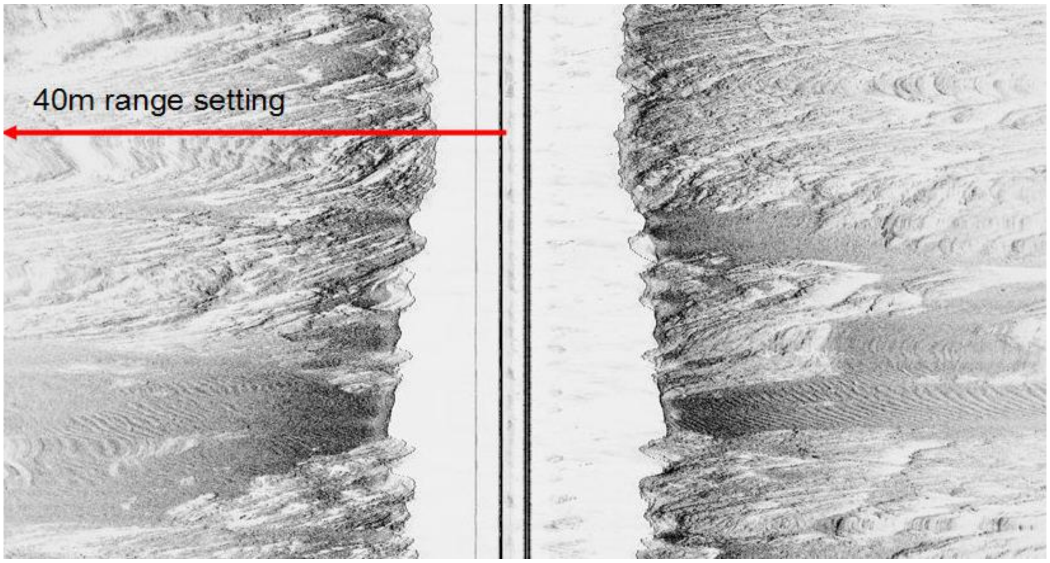

Figure A.30: Raw side scan data (plotted as a slant range waterfall) from a 500kHz GeoSwath showing the enhanced resolution.

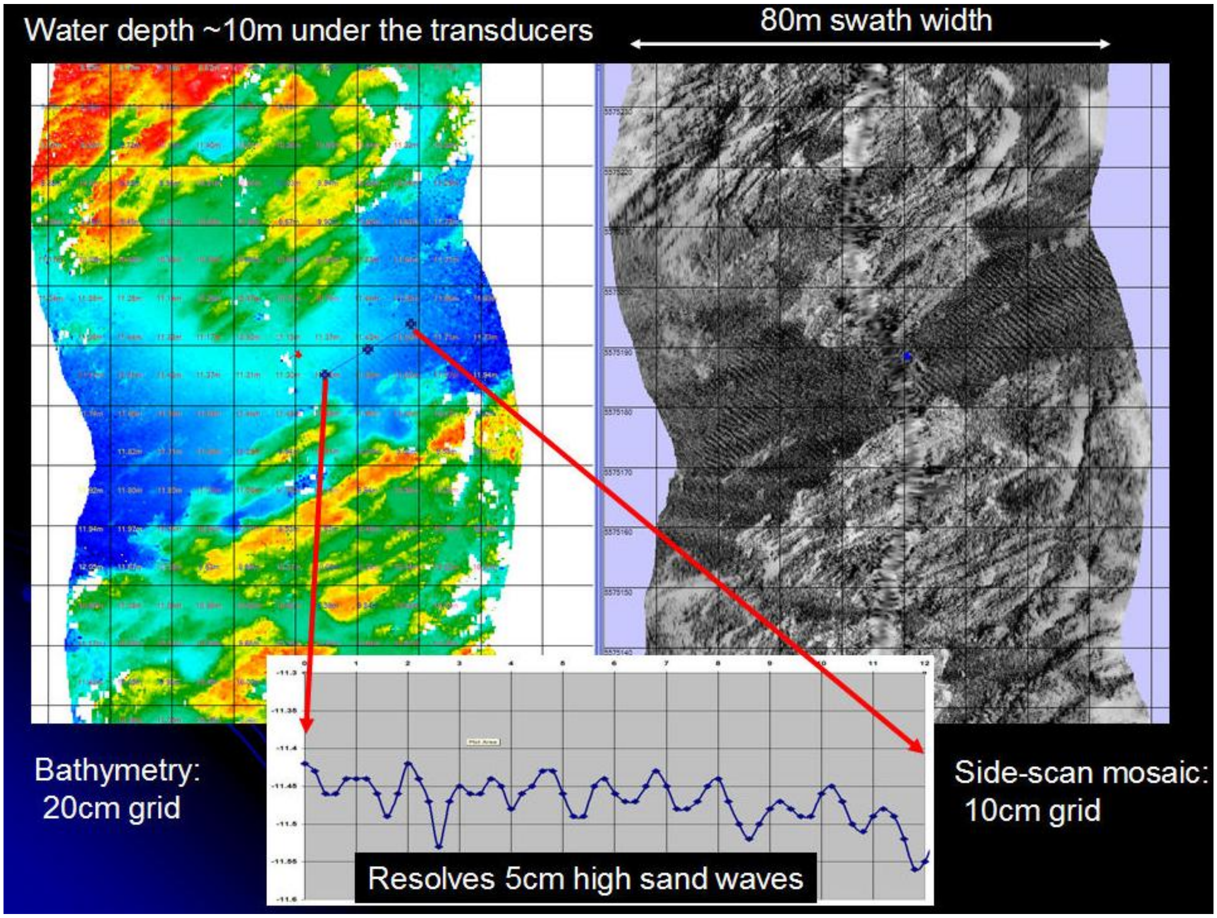

Figure A.31: Bathymetry and side scan mosaic from one swath, showing sub-centimetric resolution of seabed features (in this case some 5cm high sandwaves are detailed)

Figure A.32: The Great South Bay survey team.

Conclusions

The GeoSwath Plus 250kHz system was used to collect accurate wide swath survey data near in Great South Bay, NY. The GeoSwath collected simultaneous side scan amplitude data co-registered with the bathymetry, and was able to add several new dimensions to the information available for environmental analysis of the survey area.

This survey demonstrated the following capabilities:

- The ability of the GeoSwath sonar system to be mobilised on a very small trailerable vessel.

- The ability to perform accurate, productive survey work in very shallow (0.8m to 3m) survey situations.

- A survey of an area between 2m and 3m deep which was surveyed with 100% coverage in bathymetry and side scan at a rate of 0.25 square km/hour

- A survey of an area about 85cm deep which was surveyed with 25% bathymetry coverage and 100% side scan coverage at a rate of 0.28 square km/hour.

- Delivery of high resolution, accurate and repeatable depth maps of the survey areas.

- Delivery of true digital side-scan images aiding feature identification and ensuring detection of all significant features.

- Ability (with GeoTexture) to normalise and classify side scan data, giving texture classified georeferenced images to aid environmental mapping.

Appendix B

Stations were chosen after preliminary processing of side scan sonar data to identify areas of potentially distinct acoustic signatures. The approach was to use a stratified sampling scheme with at least one ground-truth station located in each potentially distinct acoustic signature. It was hypothesized that distinct acoustic signatures represented distinct geological/biological habitat types. A more rigorous study of the area would require at least three ground-truth samples per habitat type in order to lend statistical power to the habitat discrimination analyses conducted (see Results > Habitat mapping in text).

Table B.1: Station locations for ground-truthing in the pilot mapping study of Fire Island National Seashore, August 2006.

Station Name	Latitude	Longitude
1	40.70085	-72.9720
2	40.70333	-72.9727
3	40.69915	-72.9746
4	40.69770	-72.9801
5	40.69823	-72.9771
6	40.70335	-72.9770
7	40.69878	-72.9821
8	40.69980	-72.9858
9	40.69663	-72.9840
10	40.71203	-72.9919
11	40.70922	-72.9925
12	40.71565	-72.9898
13	40.71733	-72.9872
14	40.71335	-72.9857
15	40.71338	-72.9864

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 615/102094, May 2010

National Park Service
U.S. Department of the Interior

Northeast Region
Natural Resource Program Center
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Fort Collins, CO 80525

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